P1023 | Scot Nay

FINAL REPORT

For Option 3 Contract Year

Cost and Schedule Analytical Techniques Development

Contract NAS8-40431

December 4, 1998

SAIC
6725 Odyssey Drive
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Science Applications International Corporation
An Employee-Owned Company

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Option Year 3 Final Report

Period Covered December 1, 1997 through November 30, 1998

I. INTRODUCTION

This Final Report summarizes the activities performed by Science Applications International Corporation (SAIC) under contract NAS 8-40431 "Cost and Schedule Analytical Techniques Development Contract" (CSATD) during Option Year 3 (December 1, 1997 through November 30, 1998). This Final Report is in compliance with Paragraph 5 of Section F of the contract.

This CSATD contract provides technical products and deliverables in the form of parametric models, databases, methodologies, studies, and analyses to the NASA Marshall Space Flight Center's (MSFC) Engineering Cost Office (PPO3) and the Program Plans and Requirements Office (PPO2) and other user organizations. Detailed Monthly Reports were submitted to MSFC in accordance with the contract's Statement of Work, Section IV "Reporting and Documentation". These reports spelled out each month's specific work performed, deliverables submitted, major meetings conducted, and other pertinent information. Therefore, this Final Report will summarize these activities at a higher level.

During this contract Option Year, SAIC expended 25,745 hours in the performance of tasks called out in the Statement of Work. This represents approximately 14 full-time EPs. Included are the Huntsville-based team, plus SAIC specialists in San Diego, Ames Research Center, Tampa, and Colorado Springs performing specific tasks for which they are uniquely qualified.

II. MSFC TASKS

The basic CSATD contract calls out three major Statement of Work task areas that provide analytical techniques development activities for MSFC. Deliverables to NASA resulting under the basic tasks include an update version of the restricted NAFCOM96 to some 100 government users, delivery of an update version of unrestricted NAFCOM96 to several hundred users, three quarterly NAFCOM Newsletter to all NAFCOM users, and several hundred users, three quarterly NAFCOM Newsletter to all NAFCOM users, and documented results of dozens of ad hoc, quick turn-around taskings. In addition, the REDSTAR library was increased by 1,148 documents, 14 additional REDSTAR CD-ROM disk were developed, a web server procured to establish a web-based REDSTAR, 5 training courses were conducted to train NAFCOM users, major analytical and programming work was done to improve and expand the next NAFCOM release (NAFCOM99), and the Complexity Generator methodology was established. Accomplishments under these and other areas are discussed in the following paragraphs.

II. 1. Task 1 - REDSTAR Data Base System Maintenance and Expansion

II. 1. 1. REDSTAR Library

Approximately 1,148 documents were added to REDSTAR during 1998, bringing the total number of documents in REDSTAR to 21,187 documents. REDSTAR's growth was mainly due to the continued cataloging of documents received during 1997, along with the acquisition of four boxes of data from MSFC PP03. Further enhancement of the database was achieved by acquiring a copy of *Space 2000*; a computerized historical database of 100,000 records containing space related activity from 1926 to 2014. To insure organizational stability, and to make room for future growth, a total shift and reorganization of the REDSTAR library took place during July and August.

During Option Year 3, outside requests for REDSTAR documents and research assistance came from the following companies and NASA centers: Ball Aerospace, National Air Intelligence Center of Wright Patterson AFB, TRW, Lockheed Martin, NASA Earth Science Enterprise, JSC, LeRC, and Raytheon. Several of the requests were made as a result of locating the REDSTAR homepage on the Internet.

Data collection contacts were made during the year to answer specific inquiries, and to add data to the REDSTAR collection. These requests included the following contacts: called TRW to request back issues of TRW's *Spacelog*; called Thiokol to determine the costs of the Star-48, Star-27, and Star-20 motors; called Pratt & Whitney to determine the cost of the RL10 IIB expansion bell; called the Office of NASA Chief Financial Officer to get REDSTAR on the distribution list for the annual updates of the NASA New Start inflation index; contacted MSFC historian for assistance in locating information on "man in the can"; and called North Carolina Foam Industries concerning external tank insulation. The following web-based databases were used to locate information relating to NASA: NASA-Recon, Carl Uncover, EBSCO, AIAA, Redstone Scientific Information Center, UAH Library, MSFC Technical Reports Server, MSFC Repository, JPL Mission and Spacecraft Library, NODIS (NASA on-line directives), Foreign & U.S. Launch Vehicle Log, Air University Library and Database, NASA Technical Report Server, NASA Astrophysics Library, General Accounting Office Reports, and X.500 NASA Directory Service.

Search request topics in 1998 included the following topics: Celestri, Polar Ultraviolet Imager, "man in the can", 1990-95 global launch vehicle rates and revenues, "Cosmos on a Shoestring", Mars missions schedules, commercial-off-the-shelf cost models, active GEO satellites, space travel and tourism, LEO commercial launch vehicle projections, aft cargo carrier, utilization of external tank for space station, cost information on solar electric propulsion, articles dealing with "faster, cheaper, better", UHF Follow-on, Eagle class vehicles, EOS, RD-0120 engine cost, and FAST.

II.1. 2. Web-based REDSTAR Library & CD-ROMs

Fourteen additional CD's were completed for the third *REDSTAR on CD-ROM* effort, bringing the total number of scanned REDSTAR documents to 7,500. This third set of 2,506 documents totaled 229,218 pages. These documents were accessible from the CD-ROM using a searchable data base that includes all the REDSTAR cataloging information. In this year, we have begun to develop a Web-based version of REDSTAR that will provide a much wider access to the REDSTAR documents and provide better security of the information.

To accommodate the web-based REDSTAR, we have procured and configured a Web Server. This server will also contain other cost related web pages such as the Space Systems Cost Analysis Group (SSCAG) homepage and a NAFCOM web page. The server will be located in San Diego until the REDSTAR page is operational, then it will be located in Huntsville. The characteristics of the server are provided below.

- Compaq Proliant 6000 Server
- Dual 200 megahertz Pentium Pro Processors
- 256 megabytes RAM
- 4-18 gigabyte RAID Level 5 drives, 1 hot spare 18 gigabyte drive
- 100 megabit ethernet line
- Uninteruptable power supply
- Windows NT 4.0 operating system

We are currently developing the user interface for the web-based version of the data base. This version will include password protection, searching for documents; printing documents or search results, downloading documents, and email access to the REDSTAR librarian for specialized searches or scanning of new documents.

II. 1. 3. Data Analysis

The NAFCOM database continues to undergo changes to incorporate more useful data for NASA cost estimators. During the year we have finished the first round of intense data collection for technical information on all NAFCOM subsystems and components. This data is being placed in memo fields located in the NAFCOM database. It can be accessed through the estimating process when one needs additional information on aerospace hardware. The data, in paragraph form, will also appear in the spacecraft resumes under the Help option in NAFCOM.

The addition of new data points in the 1999 NAFCOM release includes a number of previously collected launch vehicles. These data at the stage level include: Delta II Stage 1, Delta II Stage 2, Delta II Stage 3, Minuteman III Stage 1, Minuteman III Stage 2, Minuteman III Stage 3, Minuteman III Stage 4, Peacekeeper Stage 1, Peacekeeper Stage 2, Peacekeeper Stage 3, Peacekeeper Stage 4, AFSLV Stage 1, AFSLV Stage 2, AFSLV Stage 3, AFSLV Stage 4, Atlas II Stage 1, Atlas II Stage 2, Atlas II Stage 3, Titan IV Stage 1, Titan IV Stage 2, and Titan IV Stage 3. The addition of these data makes the NAFCOM launch vehicle data base an extremely powerful estimating tool.

We continue to assist MSFC with timely response to ad hoc assignments. In the past year we have responded to many cost and technical questions concerning new and historical data. We have responded to questions and provided data on the X-33, STAR motors, data concerning current and past launch vehicles, "low cost" spacecraft, the AXAF spacecraft, studies such as "man-in-the-can", older spacecraft such as HEAO, HST, and GRO. Additional data has been supplied on cost and weights for trunnion and keel fittings, ground-base telescopes, Space Station propulsion, and information on yearly launches, both in the United States and worldwide.

II. 2. Task 2 - Development of Cost Estimating Techniques

II. 2. 1. NAFCOM

Primary NAFCOM-related activities performed this contract year included a database update for NAFCOM96, significant expansion of the NAFCOM user community, and continued development of NAFCOM99.

II. 2. 1. 1. Database Update for NAFCOM96

This year we completed and distributed an update to the NAFCOM96 model to correct a potential problem discovered in the system integration database average files, and to add four additional unmanned spacecraft data points to the database. This update was distributed to all Government Only and Unrestricted Release users.

II. 2. 1. 2. Expansion of the NAFCOM User Community

This contract year, SAIC has distributed 26 additional copies of the NAFCOM96 Government Only version and 60 copies of the Unrestricted Release version. Those requesting and receiving copies of the Government Only version of the software represented organizations in the Air Force, NASA, BMDO, DARPA, and Navy. The Unrestricted Release version of NAFCOM was distributed to 7 foreign organizations and at least 33 different US contractors, individuals, and/or universities.

II. 2. 1. 3. Continued Development of NAFCOM99

NAFCOM99, due to be released early in the next contract year, will be a major update to the current version of NAFCOM. The next version will offer several new features along with some enhanced features and of course additional data points. The most notable features that will be introduced in NAFCOM99 are the Complexity Generator, the Process Based Estimating feature, the Liquid Rocket Engine Module, and the Scientific Instruments Estimating Module. The Complexity Generator and the Process Based Estimating features are discussed in II.2.5. and II. 3. 2.

II. 2. 1. 4. Scientific Instrument Module

The Scientific Instrument Module provides the capability to estimate instruments' cost using the traditional NAFCOM methodology and a database of over 350 instruments. The majority of the instruments database was obtained from GSFC's Scientific Instruments Cost Model, with additional data being retrieved from the REDSTAR database. SAIC worked closely with the MSFC Engineering Cost Office, to develop the database and model interface for the scientific instruments module. Originally, the database was segregated by instrument class into nineteen data files. To facilitate easier filtering and database creation, all instrument classes were combined into one database file and additional fields were created for filtering data, including components fields for mechanisms, optics, detectors, and miscellaneous components.

To add an instrument system the NAFCOM user will first make that selection on the Add WBS Element screen, as shown in Figure 1. The user will then add instruments to the system using the user define, specific analogy, and/or database average options familiar to NAFCOM users. The specific analogy database includes 89 fields of information, 28 of which are used for filtering. In addition to the Scientific Instruments Class filter shown in Figure 2, users will have the option of filtering on technical characteristics such as size and measurement range, and programmatic characteristics such as contractor and contract start date.

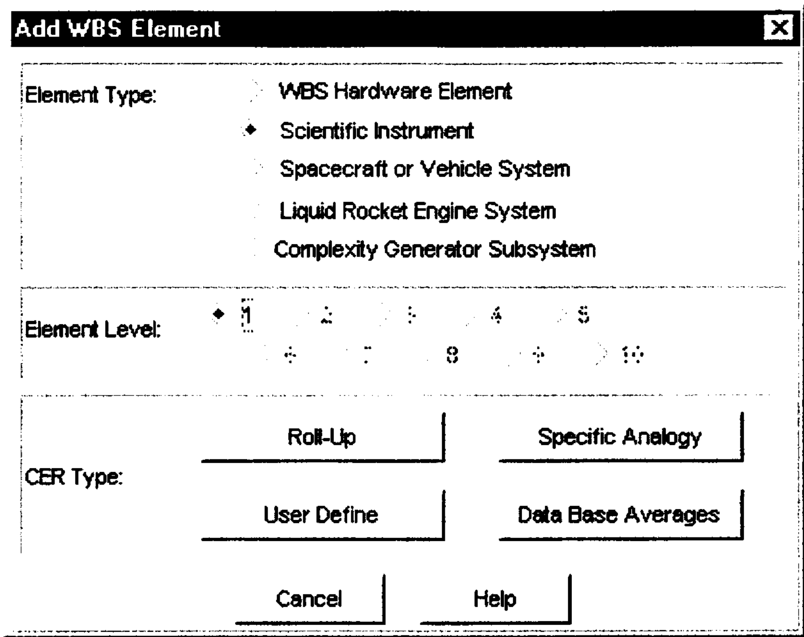


Figure 1, Add WBS Element Screen

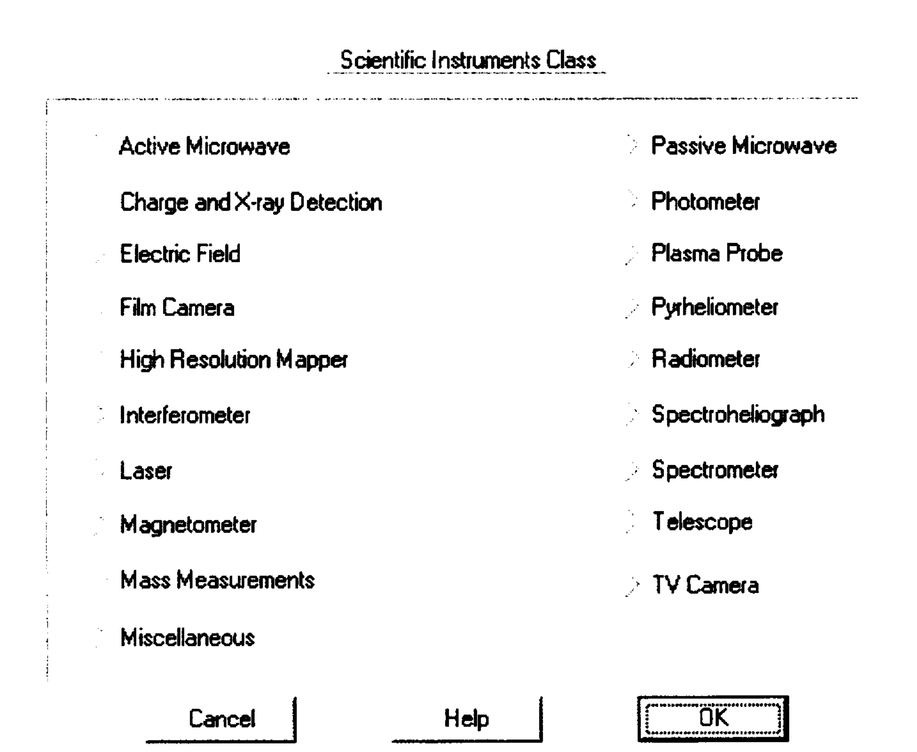


Figure 2, Scientific Instruments Class Filter

II. 2. 1. 5. Liquid Rocket Engine Module

The Liquid Rocket Engine Module in NAFCOM99 provides the capability to estimate the cost of liquid rocket engines using the estimating methodology set forth in Rocketdyne's Liquid Rocket Engine Cost Model prepared for MSFC.

The Liquid Rocket Engine Cost Model provides historically-based, parametric CERs at the engine level for estimating development and production costs of chemical propulsion, liquid propellant rocket engines in the 20 Klbs to 2000 Klbs vacuum thrust range. CERs are also provided at the component level for an alternative method of estimating the production costs. The cost model's CERs give cost as a function of size, complexity and process attributes. The model is an engineering model and is not based on regression analysis, since only a few data points were used to develop the model.

To add an engine system the NAFCOM user will first make that selection on the Add WBS Element screen shown previously in Figure 1. NAFCOM then allows the user to enter development cost inputs, and choose the detailed, component level model, or the summary, engine level model for estimating the production costs, as shown in Figure 3. Figure 4 provides the input parameters for the development and production CERs.

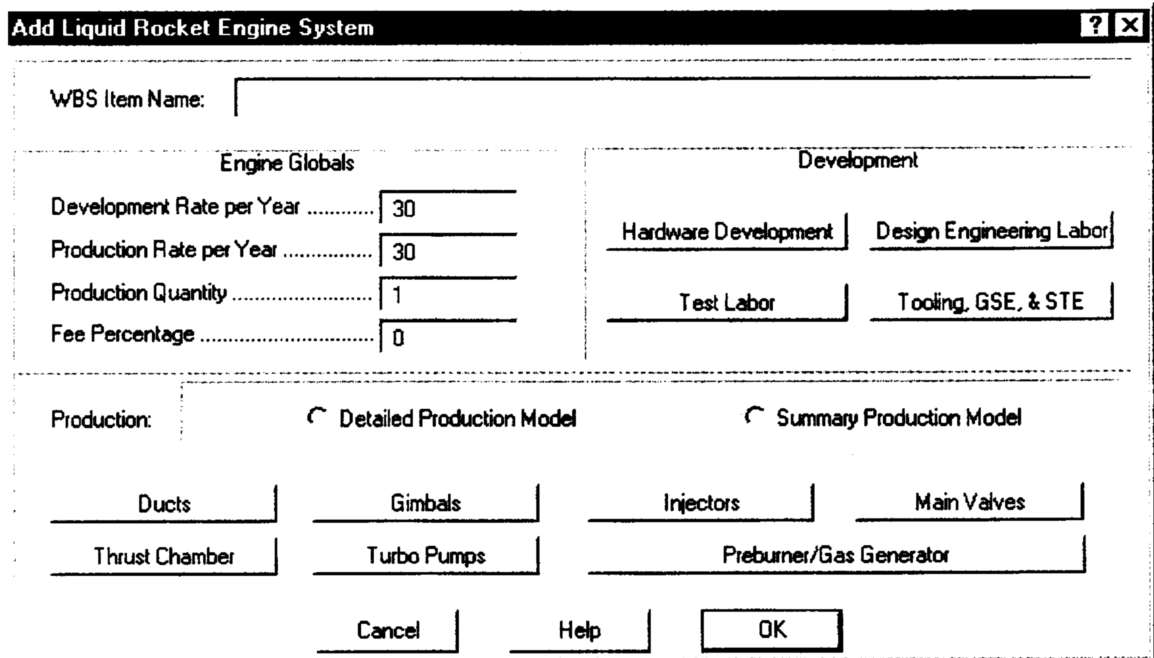


Figure 3, Add Liquid Rocket Engine System Screen

Model	Inputs	
Development	Engine Cycle/Internal Environment Complexity Engineering Design/Mfg Maturity Development Process Improvements Development Engine Fab. Time Span Test Reduction Factor	Test Frequency Tooling Availability Unit Production Cost Production Rate
Engine Level Production	Producibility Improvements Manufacturing Automation Thermodynamic Cycle Reusability Propellant Type	Chamber Pressure Thrust Level Production Quantity Production Rate
Component Level Production	Level of Manufacturing Support Degree of Outsourcing Component Type Number of Turbopump Parts	Weight Quantity Per Engine Production Quantity Production Rate

Figure 4, Liquid Rocket Engine Module Input Parameters

In preparation for adding this feature to NAFCOM99, we reviewed the Liquid Rocket Engine Cost Model, seeking guidance from part of the Liquid Rocket Engine Model's development team at Boeing. The algorithms and appropriate input screens have been incorporated into NAFCOM. The Engine System status display, additions to printouts, and help text is currently being worked.

II. 2. 1. 6. Other Features

In addition to these features, NAFCOM99 will include a notes/summary field, quicker direct access to the database, a database memo field, improved project resumes, 30 additional projects, metrics conversion for weight, and others. The notes/summary field, which has been added to the main screen, continuously shows updates to totals as elements are added or edited, and with a click to the right mouse button also allows entry and display of notes pertaining to the individual elements.

Previously, to access the NAFCOM database, the user was required to first initiate the process of adding a specific analogy element. Now, to simply view the database, the user only has to click a button in the toolbar for immediate access.

Much effort was expended this year to complete the research for technical and programmatic data for the new memo fields and to improve the project resumes. In a NAFCOM99 database, the user can select a data point, click a button, and view a technical narrative about the particular subsystem or component. In addition, the technical and programmatic data will be incorporated into improved project resumes located in the help system.

The NAFCOM database currently contains 104 projects. Data has been collected and analyzed for 30 new projects that will be included in NAFCOM99.

To satisfy numerous requests by NAFCOM users, NAFCOM99 will also accommodate the use of either kilograms or pounds as the unit of measure for weight.

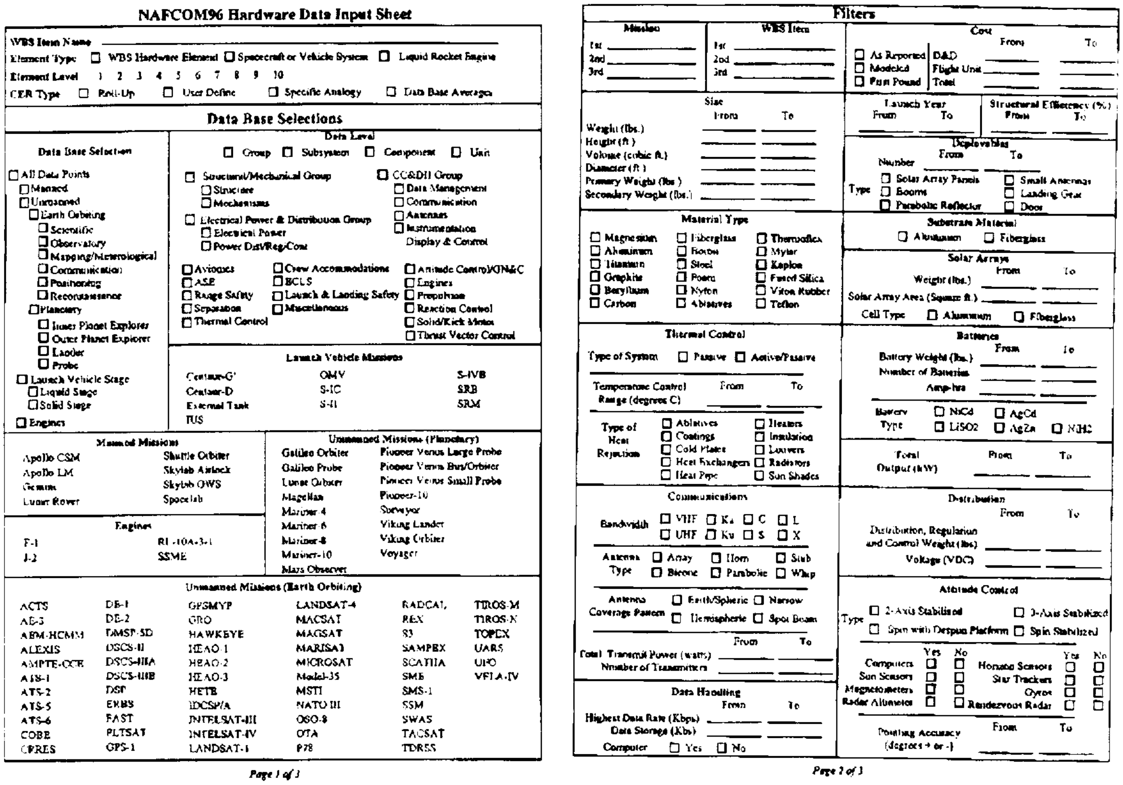


Figure 5, Sample of Data Input Sheet

In this contract year, the NAFCOM development team continued efforts to make the NAFCOM software development process more efficient. Early in the year, we created a resource-loaded network for the NAFCOM project, which uses identified tasks required to complete the project and the time required performing these tasks to generate a schedule. An accompanying Project WBS and WBS Dictionary were also created. In addition, we conducted 36 internal NAFCOM Planning, Definition and Review Meetings with NAFCOM team members. These meetings were held to track the progress of NAFCOM related tasks, and to make decisions concerning new and existing features.

II. 2. 2. NAFCOM Programming

Option Year 3 produced sweeping improvements within the NAFCOM99 model. The following paragraphs will briefly delineate the programming improvements made in order by module.

II. 2. 2. 1. Summary/Note Screen

The most readily apparent change for NAFCOM users will be the transformation of the main screen. The main screen was divided to include a summary/note screen combination in the upper right portion of the main screen display. The default setting is a summary of DDT&E, Flight Unit, Production, and Total values for the Grand Total, System, Hardware Total, and System Integration fields. If the Summary is clicked once with the right mouse button, it transforms into a note field. When the note field is double clicked, a dialog box appears to enable the user to input unique notes on any WBS element. These notes will appear within the correlating area on the NAFCOM printouts.

II. 2. 2. 2. Scientific Instruments Module

We developed a routine for adding a Scientific Instrument data point. The process required for adding an Instrument was different than adding any other data point because System Integration was already included in Instruments. This requires writing special calculation procedures and changing our rule base for handling data points in an estimate. The calculation code was very complex, making the Add Instrument routine more difficult to program than a regular WBS hardware element. The Scientific Instruments also has to be put in a special place in the estimate so the user can easily identify the instrument as having no System Integration calculated in. We successfully completed all pre-test coding of the Scientific Instruments Module and fully integrated the module into NAFCOM99.

II. 2. 2. 3. Liquid Rocket Engine Cost Model

We began the process of incorporating the Liquid Rocket Engine Cost Model into NAFCOM99. This involved the creation of numerous screens and extensive coding. The Liquid Rocket Engine Cost Model consists of 13 separate dialog boxes. There are four separate Development options and two separate Production models within the Liquid Rocket Engine Cost Model. The analysts have completed developing the algorithms for the model and the coding is 50% complete.

II. 2. 2. 4. Complexity Generator

We received the first series of data on the Complexity Generator. We began the process of programming the Complexity Generator by modifying the NAFCOM99 screens to ready them for the integration of the Complexity Generator. We developed the Electrical Power and Distribution Group Subsystem screen. As the Complexity Generator encompasses a considerable amount of information, a tab property has been integrated into the dialog boxes. This allows for the user to remain on one static screen and move back and forth between information. The coding of this module will continue as the analysts provide data.

II. 2. 2. 5. Context Sensitive Help

We developed context sensitive help for the NAFCOM99 application. This involved physically adding the help button to each dialog box within NAFCOM99. We then acquired the help index number for each dialog box and programmed the context sensitive help accordingly.

II. 2. 2. 6. Cost Sheet Viewer

The Cost Sheet Viewer was improved in several areas. White space was reduced within the Cost Sheet Viewer. We increased the size of the display screen to provide a larger display area. Also, to improve the viewing capability, selected columns have been frozen within the Cost Sheet Viewer.

II. 2. 2. 7. FBS Matrix Update

We updated the FBS matrix. This involved updating all of the NASA and OSD percentages. Along with updating the FBS Matrix, several default values in NAFCOM99 had to be updated.

II. 2. 2. 8. FBS Equation Update

We reviewed the new FBS equation with the analysts. After we studied the present coding and naming convention of the equation, we restructured the FBS equation for NAFCOM99.

II. 2. 2. 9. Inflation Indices Update

We updated the inflation indices within NAFCOM to reflect 1998 values. We verified that the inflation indices were operating correctly and they were pulling the correct values.

II. 2. 2. 10. NAFCOM99 Y2K Compliance

We tested NAFCOM99 for Y2K compliance. As we had predicted before the test procedure, NAFCOM99 was fully Y2K compliant.

II. 2. 2. 11. Copy and Paste Option

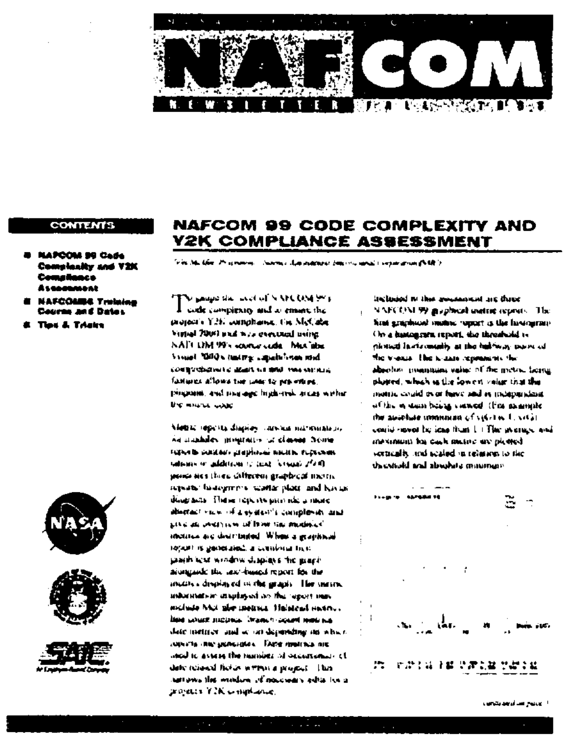
We have developed a copy and paste option that will allow the user to paste data points between separate running copies of NAFCOM. This will allow the user to copy a data point from one estimate to another. In the past, we have only been able to copy a data point and paste it in the same estimate.

II. 2. 3. NAFCOM Newsletter

In this contract year, three issues of the NAFCOM Newsletter were published and distributed to 362 NAFCOM users and others. The winter issue of the NAFCOM Newsletter introduced a NAFCOM Data Input Sheet which is now included in all NAFCOM distribution and training packages. The Input Sheet, as shown in Figure 1, assists users in collecting and organizing input parameters necessary for performing and documenting a NAFCOM estimate. This Input Sheet was developed to satisfy numerous requests made during NAFCOM training sessions.

The Spring 1998 issue featured an in-depth article about "Process Based Estimating Within the NASA/Air Force Cost Model." The article included excerpts from a paper that SAIC presented at the 1998 Joint Annual Conference of the International Society of Parametric Analysts (ISPA) and the Society of Cost Estimating and Analysis (SCEA).

The Fall 1998 NAFCOM Newsletter included a very in-depth discussion of NAFCOM's code complexity and Y2K compliance, as well as training updates and model tips and tricks. Starting with the Fall 1998 issue, the Newsletter exhibited a new, sleeker color format, as exhibited in Figure 6.


NAFCOM
NEWSLETTER

CONTENTS

- NAFCOM 99 Code Complexity and Y2K Compliance Assessment
- NAFCOM98 Training Courses and Dates
- Tips & Tricks

NAFCOM 99 CODE COMPLEXITY AND Y2K COMPLIANCE ASSESSMENT

Figure 6, Fall 1998 Issue of the NAFCOM Newsletter

II. 2. 4. NAFCOM Training

Five NAFCOM96 training sessions were held during this contract year, consisting of three Government Only classes and two Unrestricted Release classes. Estimators from AFCAA and Photon Research, who supports BMDO, attended the Government Only classes. The Unrestricted Release training sessions included analysts from Lockheed Martin (New Orleans) and Qualis Corporation.

In an attempt to boost class attendance this year we mailed registration forms to one individual at each organization that has more than one registered NAFCOM user, in addition to all users that expressed interest in training or called with comments or questions. We also distributed registration forms at one of the monthly local SCEA meetings. We were contacted by Northrop Grumman, NASA Ames Research Center, Boeing (Huntsville, AL and Huntington Beach, CA), and Lockheed Martin (Huntsville) regarding formal training courses, but no classes have been scheduled as of yet.

II. 2. 5. Complexity Generators

The Complexity Generators represent an innovative cost estimating methodology where multiple cost driving variables are identified and algorithms are developed that allow using the cost drivers to determine the costs of future programs. We are finalizing the development of the NAFCOM Complexity Generators by refining our development approach using the electrical power subsystem as a prototype for the other subsystems.

II. 2 5. 1. Approach

The approach for developing the Complexity Generators includes the step identified below. Each of the steps will be briefly described.

- Define potential cost drivers
- Develop data base of cost drivers
- Analyze data for trends and impacts
- Categorize complexity
- Develop complexity relationships
- Test and verify
- Documentation and demonstration

The potential cost drivers for the Complexity Generators have evolved over the past year. There are different cost drivers for each of the subsystems although some cost drivers are the same for all. A list of candidate cost drivers for each subsystem is shown below.

General	**Electrical Power**
Heritage	System Type
Maturity	Output Watts
Management Levels	Watts/sqft
Requirements Changes	Design Life
Contractor Experience	Battery Type
Specification Levels	Amp Hours
Attitude Control	Packaging
Stabilization Method	**Propulsion**
Number & Type of Sensors	Type of Engine
Mechanism	System Type
Dedicated Computer	Total Impulse
Pointing Accuracy	Specific Impulse
Offset Pointing Control	Total BOL Thrust
Autonomy	System Pressure
Number of Deployables	Propellant Weight
Modes of Operation	Propellant Type
Redundancy	Propellant Mass Fraction
Control & Data Handling	Pressurant Weight
Bands	Pressurant Type
Number of Transmitters	Number of Tanks
Data Storage	Tank Material
Highest Data Rate	Total Burn Time
Transmit Bandwidth	Redundancy
Transmit Power	Packaging
Antenna Type	Number of Interfaces
Number of Stored Commands	**Structure**
Computer	Structural Efficiency
Redundancy	Construction Type/Method
Communication Links	Material Type
	Volume of Enclosure
	Number & Type of Deployable/Retractable
	Number & Type of Deployable Only
	Mechanisms
	Temperature Range
	Thermal Components

Figure 7, Potential Cost Drivers

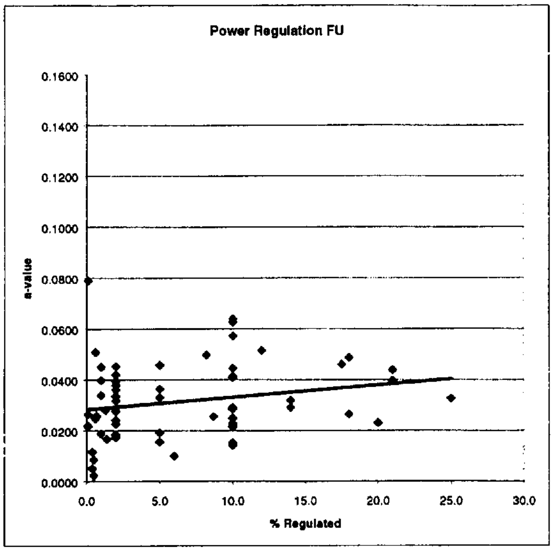
II. 2. 5. 2. Database

A data base of the cost driver information for each historical project is required to develop the complexity relationships. This data base of technical, programmatic, and cost data has been updated this year to include new cost drivers and new projects. There was also a considerable effort to validate and supplement the data already in the cost driver data base. Where actual historical data could not be located; we estimated required data using engineering judgement, analogy, or other estimating approaches. The data base consists of spreadsheets for each subsystem by mission class (e.g. Manned, Unmanned Earth Orbiting, Unmanned Planetary, or Launch Vehicle) with all potential cost drivers identified. An example of a portion of one of the spreadsheets is shown below.

Mission	System Type	Design Life (mos)	OUTPUT (W - BOL)	W/SQFT	Batt Type	Number of Interfaces	TOTAL Amphrs	Spec Level	TRL Level
ACTS	SA w/articulating panels	48	1418	10	NiCd	12	38	EO	"Flight - qualified" system, minor mod - no requal
AE-3	SA drum	12	170	4	NiCd	9	18	EO	Prototype/Engineering model tested in relevant environment; Based on previous design
AEM-HCMM*	SA w/fixed panels	12	180	35	NiCd	9	9	EO	Component/Brassboard tested in relavant environment. New design - not SOTA
AMPTE-CCE	SA w/articulating panels	12	140	31	NiCd	9	8	EO	Prototype/Engineering model tested in relevant environment; Based on previous design
Apollo CSM	Fuel Cell	0.1	4500			14		Manned	Conceptual Designs Tested Analytically or Experimentally. Advances State-of-art
Apollo LM	Battery	0.1			AgZn	16	2200	Manned	Critical functions/characteristics demonstrated. New design - SOTA
ATS-1	SA drum	36	180	3	NiCd	12	12	EO	Critical functions/characteristics demonstrated. New design - SOTA
ATS-2	SA drum	28	125	3	NiCd	12	12	EO	Critical functions/characteristics demonstrated. New design - SOTA
ATS-5	SA drum	36	151	3	NiCd	12	12	EO	Critical functions/characteristics demonstrated. New design - SOTA
ATS-6	SA w/articulating panels	24	645	3	NiCd	12	30	EO	"Flight - qualified" system. minor mod - no requal
CENTAUR-D	Battery	0.01			AgZn	3	200	Launch Vehicle	Conceptual Designs Tested Analytically or Experimentally. Advances State-of-art
Centaur-G	Battery	0.01			AgZn	6	150	Launch Vehicle	Engineering Model Tested in space. Mods with requal
COBE	SA roll/fold	12	1150	4	NiCd	9	24	EO	Engineering Model Tested in space. Mods with requal
CRRES	SA w/fixed panels	39	470	10	NiCd	9	40	EO	Engineering Model Tested in space. Mods with requal
DE-1	SA drum	12	115	3	NiCd	9	12	EO	Engineering Model Tested in space. Mods with requal
DE-2	SA drum	12	154	4	NiCd	9	12	EO	Prototype/Engineering model tested in relevant environment. Based on previous design
DMSP-5D	SA w/articulating panels	48	900	9	NiCd	12	30	AF-EO	"Flight - qualified" system: minor mod - no requal
DSCS-II	SA drum	60	520	4	NiCd	12	36	AF-EO	Critical functions/characteristics demonstrated. New design - SOTA
DSCS-III	SA roll/fold	120	1188	9	NiCd	12	96	AF-EO	"Flight - qualified" system. minor mod - no requal
DSCS-IIIA	SA w/articulating panels	120	1395	11	NiCd	12	96	AF-EO	Component/Brassboard tested in relavant environment. New design - not SOTA
DSCS-IIIB	SA w/articulating panels	120	1395	11	NiCd	12	96	EO	Engineering Model Tested in space. Mods with requal
DSP	SA w/articulating panels	84	1265	2	NiCd	14	60	AF-EO	Engineering Model Tested in space. Mods with requal
ERBS	SA w/articulating panels	24	2742	17	NiCd	9	100	EO	Engineering Model Tested in space. Mods with requal
ET	Distribution only	0.01				6		Launch Vehicle	Component/Brassboard tested in relavant environment; New design - not SOTA
FLTSAT*	SA w/articulating panels	60	2000	25	NiCd	12	72	AF-EO	Flight-proven System
Galileo Orbiter	RTG	72	570			9		Planetary	Conceptual Designs Tested Analytically or Experimentally. Advances State-of-art
Galileo Probe	Battery	0.01			LiSO	3	21	Planetary	Critical functions/characteristics demonstrated: New design - SOTA
Gemini	Fuel Cell	0.1	33			12		Manned	Conceptual Designs Tested Analytically or Experimentally. Advances State-of-art
GPS-1	SA w/articulating panels	72	830	13	NiCd	14	45	AF-EO	Critical functions/characteristics demonstrated; New design - SOTA
GPSMYP	SA w/articulating panels	90	1070	11	NiCd	14	105	AF-EO	Component/Brassboard tested in relavant environment. New design - not SOTA
GRO	SA w/articulating panels	24	5000	14	NiCd	12	300	EO	Component/Brassboard tested in relavant environment. New design - not SOTA
HEAO-1	SA w/articulating panels	6	1085	10	NiCd	12	72	EO	Critical functions/characteristics demonstrated. New design - SOTA
HEAO-B	SA w/articulating panels	18	1085	10	NiCd	12	72	EO	Flight-proven System
HEAO-C	SA w/articulating panels	6	1085	10	NiCd	12	72	EO	Flight-proven System
I-4	SA drum	84	502	2	NiCd	12	36	AF-EO	Prototype/Engineering model tested in relevant environment. Based on previous design
IDCSP/A	SA drum	60	105	2	NiCd	12	12	AF-EO	Critical functions/characteristics demonstrated. New design - SOTA
Intelsat-III	SA drum	48	178	3	NiCd	12	9	AF-EO	Critical functions/characteristics demonstrated. New design - SOTA
IUS	Battery	0.01			AgZn	3	306	Launch Vehicle	Component/Brassboard tested in relavant environment. New design - not SOTA
Landsat-1	SA w/articulating panels	12	1000	19	NiCd	9	36	EO	Engineering Model Tested in space. Mods with requal
Landsat-4	SA roll/fold	36	1430	10	NiCd	11	100	EO	Engineering Model Tested in space. Mods with requal
Lunar Orbiter	SA w/articulating panels	1	400	7	NiCd	9	12	Planetary	Conceptual Designs Formulated
Lunar Rover	Battery	0.1			AgZn	3	242	Manned	Engineering Model Tested in space. Mods with requal
MACSAT	SA drum	36	70	11	NiCd	6	11	Litesat	"Flight - qualified" system; minor mod - no requal
Magellan	SA w/articulating panels	24	1094	8	NiCd	9	60	Planetary	Component/Brassboard tested in relavant environment. New design - not SOTA
Magsat	SA w/articulating panels	4	155	8	NiCd	9	9	EO	Prototype/Engineering model tested in relevant environment. Based on previous design
Mariner-10	SA w/articulating panels	2.5	540	10	NiCd	9	20	Planetary	"Flight - qualified" system. minor mod - no requal
Mariner-4	SA w/fixed panels	2.5	700	12	AgZn	9	35	Planetary	Prototype/Engineering model tested in relevant environment. Based on previous design
Mariner-6	SA w/fixed panels	2.5	860	10	AgZn	9	36	Planetary	Prototype/Engineering model tested in relevant environment. Based on previous design
Mariner-8	SA w/fixed panels	2.5	800	10	NiCd	9	20	Planetary	Prototype/Engineering model tested in relevant environment. Based on previous design
MARISAT	SA drum	1	350	3	NiCd	12	40	AF-EO	Prototype/Engineering model tested in relevant environment. Based on previous design
Mars Observer	SA w/articulating panels	60	672	3	NiCd	9	84	Planetary	Engineering Model Tested in space. Mods with requal
Microsat	SA drum	36	10	4	NiCd	6	11	Litesat	"Flight - qualified" system, minor mod - no requal
Model-35	SA drum	60	505	4	NiCd	9	72	EO	Component/Brassboard tested in relavant environment; New design - not SOTA
MSTI	SA w/fixed panels	1	170	13	NiCd	6	30	Litesat	Component/Brassboard tested in relavant environment; New design - not SOTA

Figure 8, Cost Driver Data Base

After collecting the cost driver data base, we analyzed individual cost drivers for their impact to the cost to an electrical power subsystem. To do this we sorted the data, filtered on specific drivers, and normalized cost for several combinations of parameters. For example, we considered peak amp-hours, average amp-hours, and amp-hours per pound versus development cost, unit cost, development a-value, unit a-value, cost per pound, and technology readiness levels. The graphs shown below represent the types of trends we found.



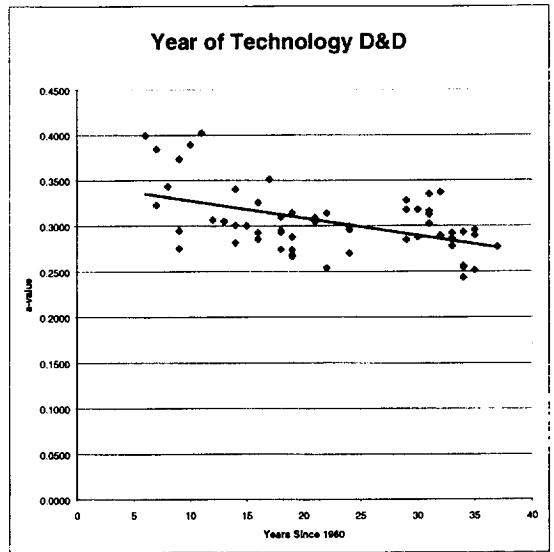


Figure 9, Data Trends

II.2. 5. 3. Cost Drivers

After analysis of the cost trends for the electrical power subsystem cost drivers, we chose the cost drivers to use and grouped the drivers into three main categories. The grouping of the cost drivers into categories allows us to apply engineering judgement to the application of the individual cost drivers. For example, if we strictly applied statistical measures to determine the coefficients for the complexity equations and used each cost driver as a dependent variable, then some of the cost drivers would have an inverse effect on the cost (as the driver increased in complexity the cost would go down). The categories of complexity are shown below for the electrical power subsystem.

- **Inheritance**
- **Technical Complexity**
  - Output Power
  - Storage Capacity
  - Year of Technology
  - Power Regulation
  - Design Life
- **Project Management**
  - Manufacturing Management
  - Funding Availability
  - Risk Management
  - Integration Complexity
  - Design Management
  - Pre-phase C/D Studies

Using the data from analysis of cost drivers for trends, we weighted each of the cost drivers within the three categories in relation to one another. For example, Year of Technology has a much larger impact on the cost than does the Design Life. For Inheritance, Technical and Project Management, we developed a complexity scale from 0 to 100. Where 0 represents lowest complexity and 100 represents highest complexity. Using the cost drivers data base we determined the complexity for each of the complexity variables. We then used multiple least squares regression to determine the coefficients for the complexity equation.

We developed a prototype of the Complexity Generator screen for the electrical power subsystem to demonstrate its use. This prototype screen was presented at the NASA Cost Estimating Symposium and to the Air Force Cost Analysis Agency. The screen allow the user to change one or more cost drivers and to see the impact on the cost estimate. The prototype screen is shown below.

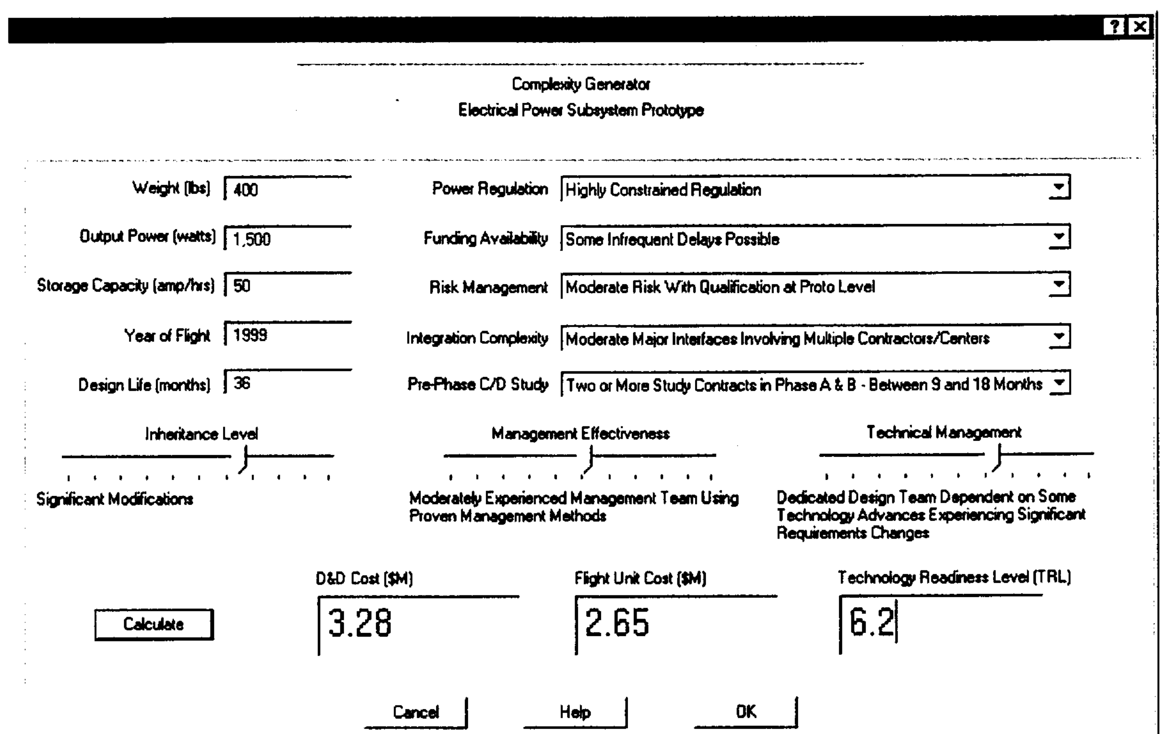


Figure 10, Prototype Complexity Generator Screen

We are currently refining the complexity relationships and testing the output of the cost estimating equations.

II. 3. Task 3 - Development of Schedules, Plans and Requirements

In Option Year 3, SAIC provided schedule analysis for several projects in Program Development and began the development of a subsystem schedule estimating model based on developmental processes. These activities are summarized in the following paragraphs.

II. 3. 1. General Scheduling

Schedule analysis and development were performed on a number of projects including included Space Based Laser (SBL), Material Science Research Rack (MSRR), ASTOR, and AIRSEDS. These are short-term, quick turnaround tasks to support Quarterly Reviews and other briefings with updates and further schedule details. Updates for these projects were required every few months and all were completed in a timely manner.

II. 3. 2. Process-Based Subsystem Schedule Estimating

During this past year SAIC has continued efforts to develop a schedule estimating model based on subsystem development processes. After research of REDSTAR schedule data, design handbooks, guidelines, and technical papers, a preliminary schedule at the process level was developed for each major subsystem (i.e. structure, thermal, avionics, and propulsion). The processes and their relative schedule duration were reviewed with discipline engineers in the Preliminary Design Office to ensure accuracy and completeness. A detailed set of schedule drivers was also identified for each subsystem. The drivers were categorized into one of four major headings: 1) Management Efficiency 2) Requirements Changes 3) Design Inheritance and 4) Technical Complexity. The list of schedule drivers was then used to develop a preliminary model input form. User selections on the input form will be used to calculate individual process duration, thus determining overall subsystem schedule. Future efforts will focus on detailed algorithm development and programming. The schedule estimating model will be incorporated as a module in the NASA Air Force Cost Model (NAFCOM).

III. OTHER TASKINGS

In addition to the work performed directly for MSFC, synergistic tasks were performed for other NASA elements and the Air Force Cost Analysis Agency. These tasks were funded by organizations other than the MSFC Program Development. Some of these were direct extensions or expansions of basic contract efforts. Others made use of the REDSTAR library, the NAFCOM model and database, and analytical techniques developed under the basic contract and therefore could be performed cost effectively and in much short time than if they had been done under separate contracts.

Those tasks funded by the NASA Comptroller were the continued development of the

Space Operations Cost Model, the calibration of PRICE Systems data for NASA users, partial funding of a SAIC cost analyst at the Ames Research Center, development of REDSTAR CD-ROMs and web-based REDSTAR, and augmentation to NAFCOM development.

The MSFC Science and Engineering Directorate continued the SAIC assessment and validation of the COMPRE model this contract year. Ames Research Center funded the remaining portion of the SAIC cost analyst at Ames. The MSFC Microgravity Office continued this year to fund enhancements and updates to the Microgravity Experiment Cost Model that we had developed for them earlier.

The Air Force Cost Analysis Agency (AFCAA) provide funding and taskings in several areas. We provided an independent assessment of the EELV Cost Analysis Requirement Document, served as a team member on the Air Force EELV Investment/Financial Analysis Team, and made a number of Air Force desired enhancements to NAFCOM.

These other taskings are described in the following paragraphs.

III. 1. Space Operations Cost Model (SOCM)

The NASA Space Operations Cost Model (SOCM) development study is an ambitious task to develop a NASA agency-wide operations cost model. Operations types include robotic planetary and Earth orbiting science missions, as well as transportation systems, space facility, and ground facility operations support for robotic and/or human spaceflight missions. At the end of 1997, prototype models were operational for robotic space science missions and plans were underway for formulation of the other modules. In this contract year, these prototypes have been iteratively refined based on input from a growing user community and have gained acceptance in the costing community. Also, several prototypes for modeling launch systems and orbiting space facilities have been developed and are leading to innovative approaches for evaluating operational requirements of large NASA projects.

III. 1. 1. Summary of Activities

As the Operations Cost Model Steering Committee progresses in understanding key cost and technology issues associated with launch systems and the ISS, our membership has more than doubled. Added members include experts from KSC for launch operations, LaRC for STS and aircraft reliability and maintainability, MSFC for launch vehicle design, economics, and marketability, and JPL for ISS logistics and support assessments. The current Operations Cost Model Steering Committee members are shown below. Del Wilson from NASA HQ is the Chairman and Mark Jacobs from SAIC is his deputy.

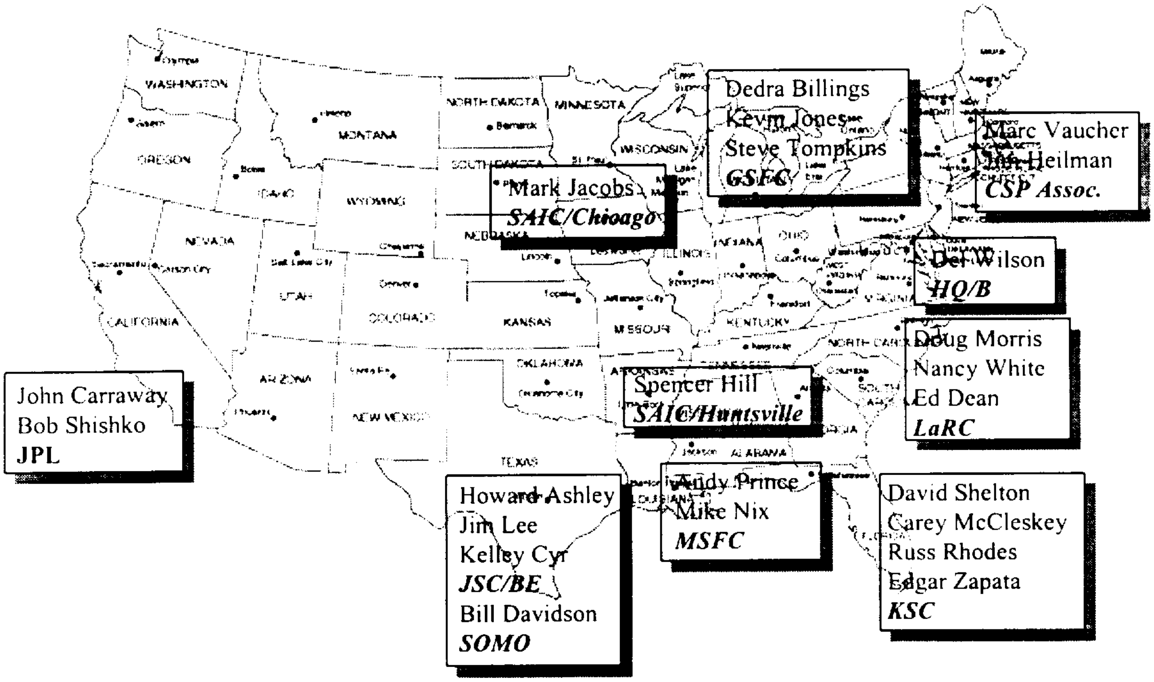


Figure 11, NASA Operations Cost Model Steering Committee Members (December1998)

As our team develops approaches to capture operations costs for near-term RLV/ELV systems and the ISS, we identify ways these approaches can be used as the basis for evaluating mid- and far-term concepts including lunar and Mars bases and interplanetary transportation systems. Plans for modeling Human Spaceflight (HSF) projects are under review and include developing a system interface that can access each SOCM module and HSF-customized submodules. These plans will be evolved over the next study year.

The new SOCM Module Family is shown below. There are four modules currently in rapid prototype development mode. The first two, Robotic Earth Orbiting and Planetary, share a common methodology with mission-unique input sets. The Launch Systems Module is being integrated at SAIC using inputs from MSFC, KSC, and LaRC. SAIC is also integrating the Space Facilities Module using inputs from JPL ISS modeling and data collection efforts. The Human Spaceflight Module, covering lunar/Mars exploration missions, will be developed from derivatives of the other four modules.

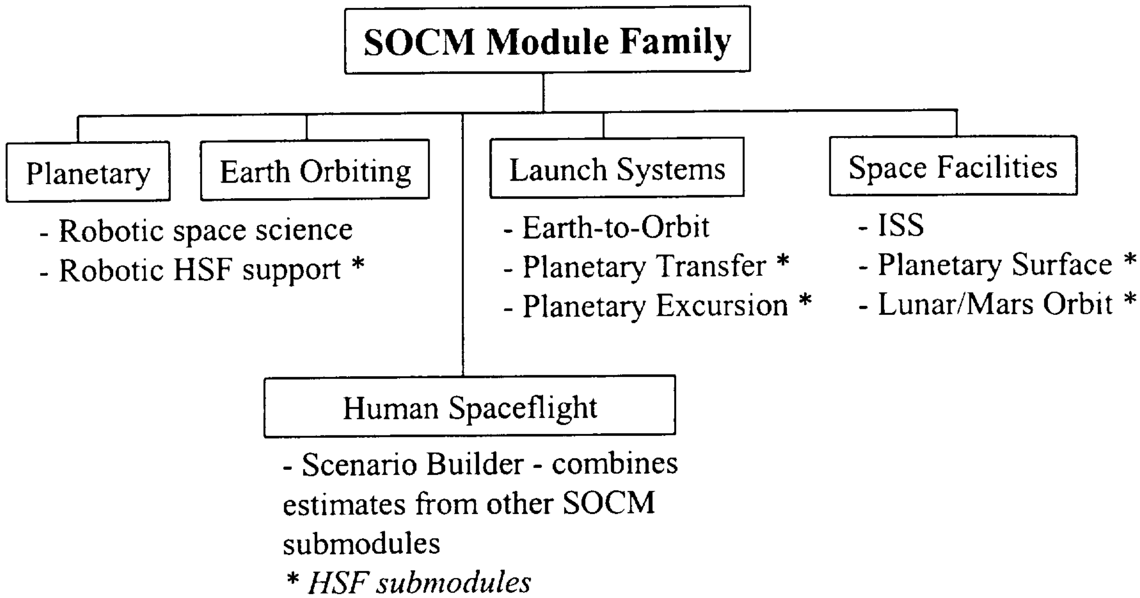


Figure 12, SOCM Module Family

Near-term plans include (1) completion of a Version 1.0 for the Earth Orbiting and Planetary Modules with integrated help menus and documentation, (2) integration of the LaRC Reliability and Maintainability Analysis Tool (with help from Old Dominion University) and the KSC Vision Spaceport Study into the Launch Systems Module prototype, and (3) completion of the ISS operations prototype by JPL. After these prototypes become operational, modeling efforts will focus more on HSF lunar/Mars missions.

This annual report summarizes Steering Committee activities; rapid prototype model (RPM) development effort status/descriptions for each module; study products, presentations, applications; and future plans.

III. 1. 2. SOCM Steering Committee Activities

The SOCM Steering Committee has added new members to support development of the Launch Systems and Space Facilities modules. These projects have a complex set of interacting cost drivers that have various impacts on life cycle costs, economics, and marketability. Our team is focusing on providing the necessary outputs characterizing operational support requirements to facilitate overall system life cycle analyses. A key objective for modeling operations is to capture the effects of advanced technology insertion in the flight and ground systems on support costs (post-development). As we generate prototype modules for advanced system concepts, the Steering Committee and SOCM user community continue to provide valuable feedback and direction to ensure reasonable accuracy for technology forecasts and cost impacts.

Four Steering Committee Meetings were held over the past year. The first was at NASA JSC in January and included a 1-day SOCM training session in one of JSC's training facilities. At the NASA HQ/GSFC March meeting, our team was given tours of the operations centers for HST and TRACE. JPL provided a tour of the PDC including a SOCM demonstration at the June meeting. In August, the team met at NASA LaRC and focused on the prototyping activities supporting the Launch Systems (RLV) and Space Facilities (ISS) modules.

Also over the past year, several other operations centers have been visited including Mars Pathfinder, Mars Surveyor, and the New Millennium Deep Space One facilities at JPL. These tours provide valuable insight into the working level concerns and issues that drive ground system requirements, designs, and advanced technology insertion.

III. 1. 3. RPM Status/Descriptions for Specific SOCM Modules

SOCM currently includes five modules that have some estimating methodology similarities, but each with a unique set of cost drivers and estimating categories. Prototypes exist for four of the modules (HSF mission prototyping is planned for 1999) and a final Version 1.0 of the Earth Orbiting and Planetary Modules should be complete early next year.

Data collection efforts have continued and are distributed among almost all study team members. Technical, programmatic, and cost information is collected for recent, near-term, and future mission concepts from the mission set shown here. The model development effort combines constructive and CER-based approaches and has the flexibility to utilize whatever information is available. The model's performance is continually enhanced as more information is collected improving our team's understanding of key issues. The prototyping activities focus on recent and near-term mission requirements and attempt to capture the differences for past and future projects by using a cost driver input set that compares various operations support characteristics to present-day State-of-the-Practice (SoP) technology levels.

NASA Center	Conventional Approach (past projects)	Use of Low Cost Modern Business Practices (current projects/SOP)	Future Missions (future projects/SOA)
Goddard Space Flight Center (GSFC)	Gamma Ray Observatory (GRO) Hubble Space Telescope (HST) Energetic UV Explorer (EUVE)	Advanced Composition Explorer (ACE) Far UV Spectroscopic Explorer (FUSE) Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) X-Ray Timing Explorer (XTE)	Midex (MAP, IMAGE) SMEX (TRACE, FAST, SWAS, WIRE) ESSP EOS NMP EO Missions
Marshall Space Flight Center (MSFC)		Advanced X-ray Astrophysics Facility (AXAF) Space Station	Mars Exploration Advanced Launch Vehicles
Johnson Space Center (JSC)	Shuttle Orbiter	Space Station	Mars Exploration
Jet Propulsion Laboratory (JPL)	Galileo Magellan Voyager	Discovery Program (Mars Pathfinder, NEAR/APL) Mars Global Surveyor (MGS)	New Millennium DS Missions Discovery Program (Lunar Prospector, Stardust) Pluto Flyby
Kennedy Space Center (KSC)	Shuttle Orbiter		HRST, RLV

Figure 13, SOCM Reference Mission Set

Capturing advanced technology impacts is a key objective for the modeling effort to improve the cost community's understanding of life cycle cost (LCC) trades from investments in flight and ground hardware and operations systems. As the SoP advances inserting improved technologies into new missions, LCC can be reduced for missions with similar levels of performance to historical analogies. However, if advanced technology is applied to maximize performance, LCC will eventually increase. The following figure graphically characterizes this relationship. Inputs for the SOCM modules compare a concept's requirements and advanced technology implementation to SoP values to develop relative differences that can be correlated to cost differences (that can either increase or decrease operations costs).

SOCM module status and description summaries are provided in the following paragraphs.

Planetary and Earth Orbiting Modules. Several iterations have been completed with these modules incorporating feedback from a growing user community and enhancing the capabilities and performance with each RPM version. Enhancements include:

- Revised estimating methodology using multiple Level 1 FTE ranges separating engineering, navigation, and science operations
- New Earth orbiting science drivers based on inputs from NASA GSFC Code 600/900 scientists
- Incorporation of SOMO operations services costs
- File integration feature enabling combinations of multiple SOCM runs
- Separate versions for Office '95 and '97 on PC and Macintosh systems

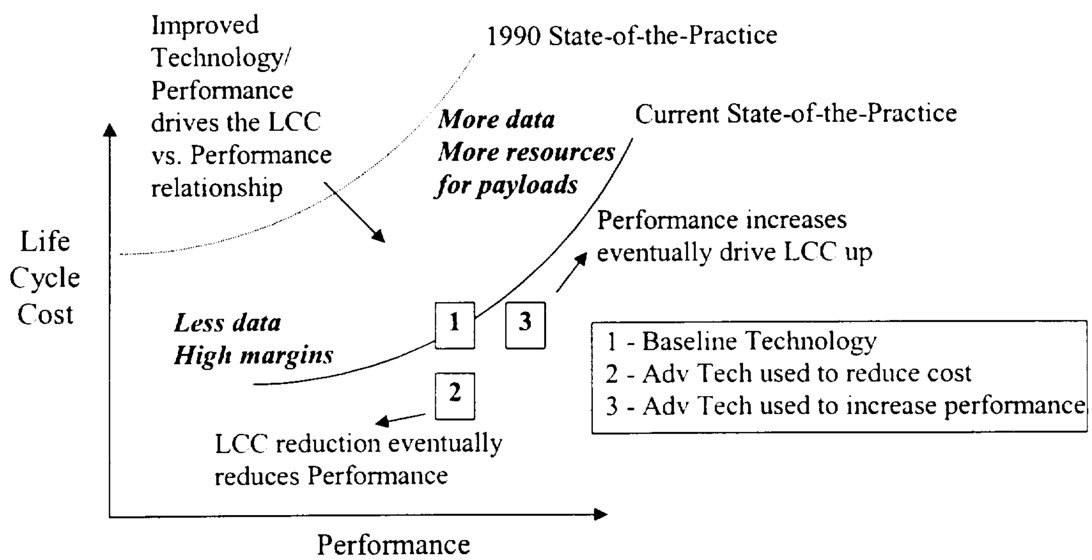


Figure 14, Capturing Advanced Technology Application

A key feature of the Planetary and Earth Orbiting modules is the ability to generate multiple output formats, as shown on the following page. These output options include 13 "traditional" functions that correlate to past project data collected, an activity-based output separating activity requirements for each major project element, and a high-level summary separating flight/engineering, navigation, and science support. Providing multiple result formats facilitates flexibility for unique model applications such as determining specific impacts of adding payload items to a mission or estimating post-flight data analysis staffing/cost requirements.

<u>Launch Systems Module</u>. The Launch Systems RPM has progressed significantly over the past year. The current approach estimates staffing and costs for 12 launch operations support functions based on a characterization of the launch system concept's complexity and reliability. Inputs include launch vehicle system and subsystem design and technology descriptions, component/subsystem reliability information, and other cycle time impacts. The model estimates start-up (mostly facility development) and steady-state operations costs and includes information to characterize cycle time (or flight rate) requirements based on the number of bays provided in key spaceport facilities. This approach is summarized schematically in the "High-Level Overview of the Launch System Estimating Methodology" chart.

The foundation for the estimates developed are Complexity vs. Reliability matrices developed for each of the 12 operations support functions. This approach characterizes the lowest cost system (from an operations perspective) as the least complex and most reliable design. During development of these matrices, select STS and Air Force aircraft data is used to determine staffing, cost, and cycle time ranges based on different complexity and reliability assumptions.

LEVEL 2 MISSION OPERATIONS COST, FTE, FTE/yr ESTIMATE			1999 constant FY $K
Mission Name	**Phase E *Cruise***	**Phase E *Encounter***	***Phase E* Total**
1.0 MISSION PLANNING & INTEGRATION	0.0	0.0	0.0
2.0 COMMAND/UPLINK MANAGEMENT	0.0	0.0	0.0
3.0 MISSION CONTROL & OPS	0.0	0.0	0.0
4.0 DATA CAPTURE	0.0	0.0	0.0
5.0 POS/LOC PLANNING & ANALYSIS	0.0	0.0	0.0
6.0 S/C PLANNING & ANALYSIS	0.0	0.0	0.0
7.0 SCI PLANNING & ANALYSIS	0.0	0.0	0.0
8.0 SCIENCE DATA PROCESSING	0.0	0.0	0.0
9.0 LONG-TERM ARCHIVES	0.0	0.0	0.0
10.0 SYSTEM ENGINEERING, INTEG, & TEST	0.0	0.0	0.0
11.0 COMPUTER & COMM SUPPORT	0.0	0.0	0.0
12.0 SCIENCE INVESTIGATIONS	0.0	0.0	0.0
13.0 MANAGEMENT	0.0	0.0	0.0
Project Direct Total	0.0	0.0	**0.0**
Operations Services	0.0		**0.0**
Project TOTAL			**0.0**

LEVEL 2 MISSION OPERATIONS $,FTE,FTE/yr ESTIMATE - Phase E Encounter (or Cruise)					
Mission Name	a) S/C	b) Science	c) Grnd Sys	d) Nav Sys	TOTALS
I PLAN	0.0	0.0	0.0	0.0	0.0
II COMMAND	0.0	0.0	0.0	0.0	0.0
III MONITOR	0.0	0.0	0.0	0.0	0.0
IV ANALYZE	0.0	0.0	0.0	0.0	0.0
V DEVELOP					
VI DATA SERVICES	0.0	0.0	0.0	0.0	0.0
VII OVERHEAD SERVICES	0.0	0.0	0.0	0.0	0.0
TOTALS->	0.0	0.0	0.0	0.0	0.0

LEVEL 2 MISSION OPERATIONS ESTIMATE - Phase E			
Mission Name		*Costs are FY* 1999	
	Cruise	Encounter	TOTALS
Annual FTE/$ Estimates			
Flight Ops	0.0	0.0	
Nav/Tracking Ops	0.0	0.0	
Science Ops	0.0	0.0	
Total FTEs/yr	***0.0***	***0.0***	
Annual FTE Cost	***$0.0***	***$0.0***	***$0.0***
Annual Ops Serv.			***$0.0***
Summary			
Phase duration (mo)	*0.0*	*0.0*	*0.0*
Total Ops Services			***$0.0***
Total FTE $M	***$0.0***	***$0.0***	***$0.0***
Total $M			***$0.0***

Figure 15, SOCM Planetary and Earth Orbiting Module Output Options

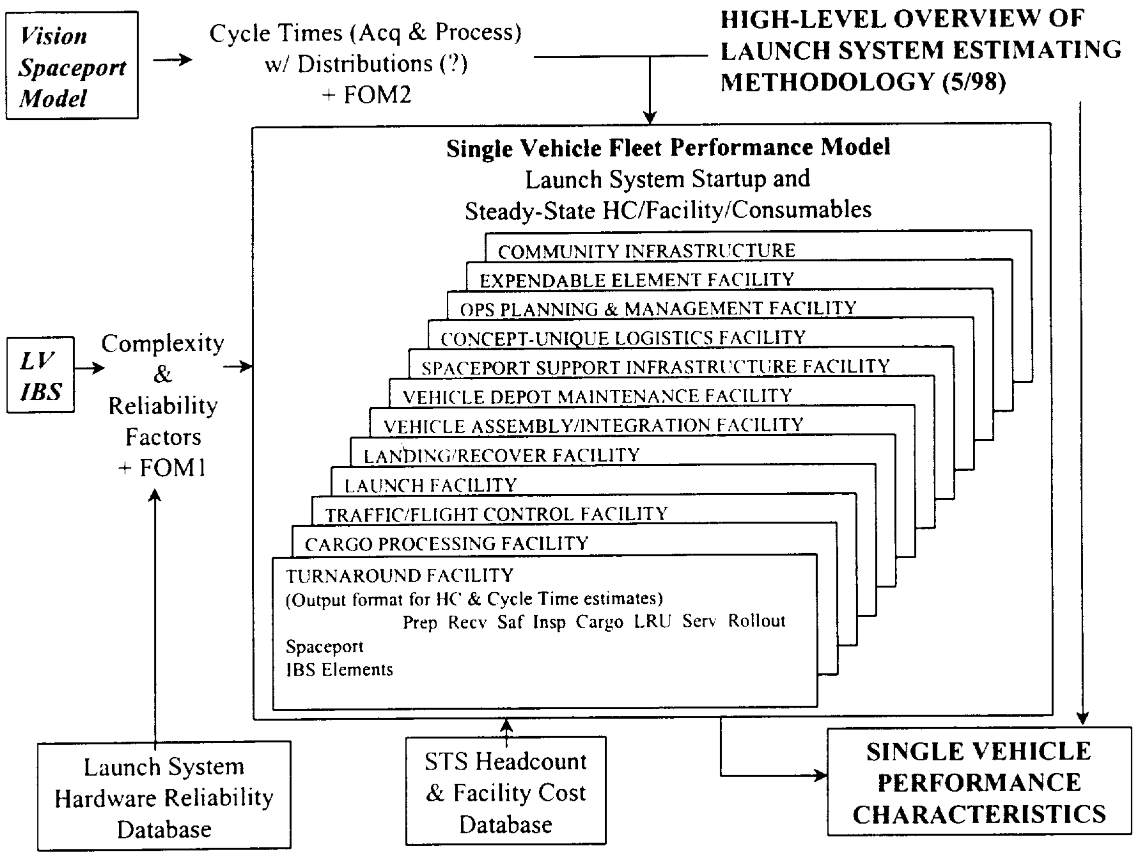


Figure 16, High-Level Overview of Launch System Estimating Methodology

A sample complexity/reliability matrix for the Turnaround Facility/function is shown below. The values in the cells represent total headcount associated with a given complexity/reliability ranking. Separate matrices are used for labor, facility, GSE, and material/ODC costs for each of the 12 operations support functions. The complexity ranking compares the average time required per maintenance action and reliability captures the number of maintenance actions required.

Separate tables for Labor $, Facility & GSE $ Adj Factors, and Materials/ODC's

Operations Costs Reduced Through Enhanced Reliability →

Headcount
TURNAROUND

Cx Value \ Rx Value	1	2	3	4	5	6	7	8	9	10
1	6449	6103	5782	5470	5153	4821	4474	4118	3764	3426
2	6872	6495	6164	5858	5558	5246	4910	4550	4176	3807
3	7333	6901	6537	6224	5939	5656	5350	5008	4628	4230
4	7861	7345	6920	6573	6285	6029	5769	5472	5114	4700
5	8491	7865	7344	6925	6598	6346	6133	5910	5620	5222
6	9256	8502	7857	7324	6907	6606	6405	6265	6106	5802
7	10178	9291	8508	7833	7276	6851	6576	6460	6476	6447
8	11262	10247	9332	8515	7796	7188	6718	6440	6512	7163
9	12502	11365	10332	9393	8539	7763	$\boxed{7057}$	6351	5716	5145
10	13752	12502	11365	10332	9393	8539	7763	6986	6288	5716

Separate tables for each Spaceport Facility

↑ *Operations Costs Reduced Through Reduced Complexity*

STS has been temporarily linked to the Cx=9/Rx=7 cell

Figure 17, Sample Complexity/Reliability Matrix

Because this approach provides only an operations-based perspective of a launch system concept's performance, results need to be integrated with other system life cycle analysis tools to evaluate overall system performance, as shown in the figure below. These tools include development models to estimate non-recurring and recurring launch vehicle costs, market and economic models to characterize affordability, and simulation tools to integrate the results and aid end-to-end system design optimization.

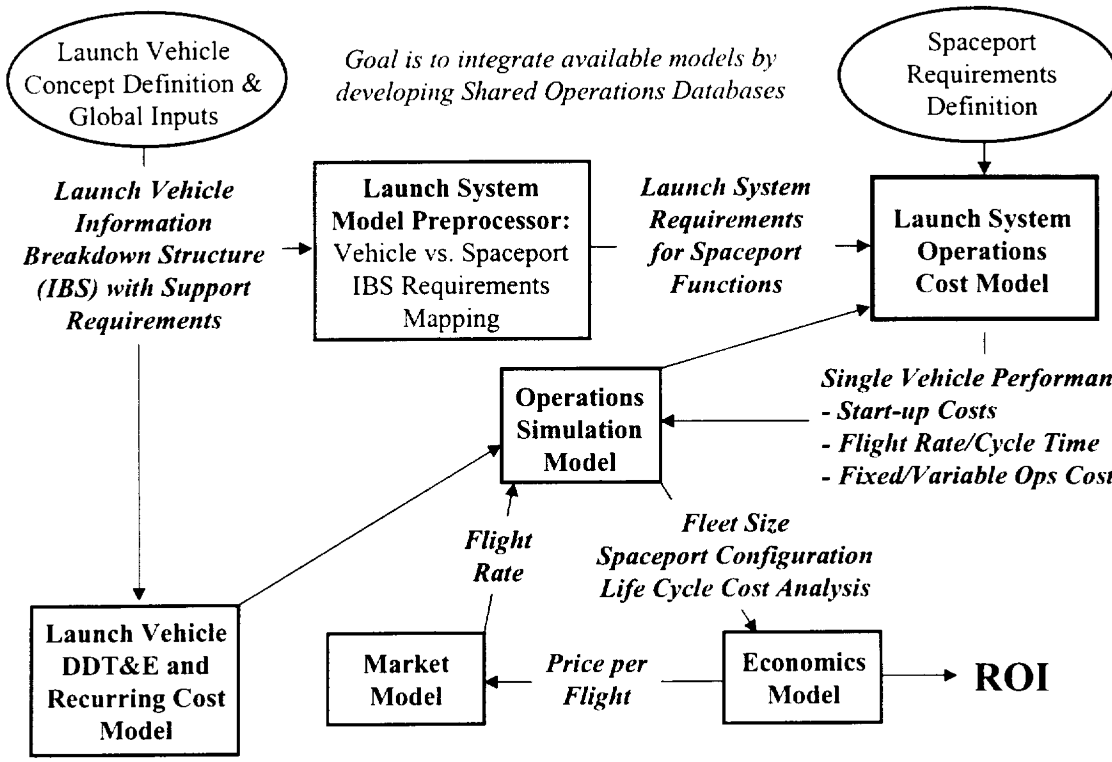


Figure 18, Integration of Models to Support Life Cycle Launch System Analyses

<u>Space Facilities Module</u>. The Space Facilities Module is currently under development by JPL and will be integrated into SOCM by SAIC later in 1999. The design basis for the RPM effort is ISS and new data is being collected from the JSC Space Station Office. The current prototype includes 20 output cost categories and many "non-cost" performance outputs to characterize operational performance. Sample formats of this module's outputs are provided on the following page. The ISS-based prototype is currently mid-way in development and should be complete by the middle of 1999.

Model for Estimating Space Station Operations Costs (MESSOC)

Return | Print | Help | Run MESSOC | Chart

ANNUAL COST BY FUNCTION	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
SSCC/ESC Maintenance and Sup										
Training Operations										
Flight Design										
Flight Planning										
Flight Implementation										
WP Sustaining Engineering										
SSE/TMIS/Information Systems										
Intermediate/Depot-Level Repairs										
Flight Equipment Spares										
Element Processing										
Station Consumables										
GSE Maintenance and Support										
Other Integrated Logistics Support										
User Integration										
Flight Crews Pay and Allowances	$0.39	$0.33	$0.28	$0.33	$0.39	$0.28	$0.33	$0.28		
Integration Mgmt and Inst Support										
Program Taxes and Reserves										
NSTS/ELV Launch Services										
Data Handling Services										
TDRSS/NASCOM Services										
Total (millions)	$0.39	$0.33	$0.28	$0.33	$0.39	$0.28	$0.33	$0.28		

Model for Estimating Space Station Operations Costs (MESSOC)

Return | Print | Help | Run MESSOC | Chart | Assessment

Sum of Nominal Operations Costs	$3.29
PV (BaseFY$) Discounted to First Ops FY	$2.11
PV (FY98$) Discounted to First Ops FY	$1.89
PV (FY98$) Discounted to FY98	$1.11

SUMMARY ITEM	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cost Summary										
Nominal Operations Costs	$0.49	$0.43	$0.37	$0.47	$0.57	$0.43	$0.54	$0.00		
Base FY Operations Costs	$0.43	$0.37	$0.31	$0.37	$0.43	$0.31	$0.37	$0.31		
FY98 Operations Costs	$0.39	$0.33	$0.28	$0.33	$0.39	$0.28	$0.33	$0.28		
Station Summary										
Reboost Strategy	1	1	1	1	1	1	1	1		
Logistics Rendezvous Altitude (km)	450	450	450	450	450	450	450	450		
Station Reboost Altitude (km)										
Station Weight										
Number of Pressurized Modules										
Pressurized Volume										
Pressurized ORU Storage Volume										
Crew Summary										
Crew Size	7	6	5	6	7	5	6	5		
Crewhours Available										
Max Allowed EVA Crewhours										
Total EVA Crewhours										
EVA Crewhours Available										
Upmass/Downmass Summary										
On-Orbit Consumables										
ORUs Delivered										
Growth Weight										
Service Modules Delivered										
Upweight Available										
Downweight Available										
Transportation Summary										

Figure 19, Sample Output from the Space Facilities/Space Station Module

III. 1. 4. SOCM Study Products, Presentations, and Applications

Available SOCM study products, presentations, and applications developed this contract year are listed in the following tables.

Item	Description
SOCM Planetary and Earth Orbiting Rapid Prototype Models (2e, 2f, 2g)	Rapid prototypes developed to incorporate user feedback, test estimation methodology options on various data sets, and as a communication aide between SOCM modeling teams, data collection teams, and the user community. SAIC is leading the development of these rapid prototypes and serving as a point-of-contact to collect and integrate information/data/findings.
SOCM User Manual and Guide (2g)	A draft revised manual for version 2g is complete including an overall model methodology description.
Launch System RPM	Preliminary tool covering launch operations requirements for a turnaround facility
Space Facilities RPM	Updated version of the Model for Estimating Space Station Operations Costs (MESSOC) using current ISS program data and modern interface software.

Figure 20, SOCM Study Products

Item	Description
Quarterly Steering Committee Reports (Jan/Mar/Jun/Aug)	SAIC status updates for specific SOCM modules and presentation of advanced concepts; Includes data collection, performance assessment, and testing results for latest rapid prototype versions.
Lessons Learned presentation to the ISE Program at NASA HQ (Apr)	Provided a "Lessons-Learned" briefing to the ISE cost community to use as a reference for developing advanced cost modeling concepts.
NASA Cost Symposium at LaRC (Sep)	Shared descriptions of SOCM modeling approaches and application experiences with the NASA cost community.
Space Systems Cost Analysis Group Meeting at Motorola (Oct)	Provided input to the SSCAG Operations and Support subgroup to facilitate better understanding of operational issues requiring attention

Figure 21, SOCM Study Presentations

Item	Description
University Explorer (UNEX) AO Evaluation	Used the Earth Orbiting Module to estimate costs for low-cost university missions ranging from less than $0.5M/yr to $2-3M/yr; Results were generally within 20% of proposed costs.
Discovery Program AO Evaluation	Over 30 proposals for planetary missions were evaluated with the Planetary Module; Results were within 10-20% of proposed costs for most mission candidates which varied substantially in annual staffing/cost requirements.
Medium-Class Explorer (Midex) AO Evaluation	Over 30 proposals for Earth orbiting space science missions were evaluated using the Earth Orbiting Module; Results were within 10-20% of proposed costs for most mission candidates which ranged from $1M/yr to over $10M/yr for MO&DA.
Independent estimate of the GLAST mission for the SEU Office at GSFC	Provided an estimate to the Structure and Evolution of the Universe Program Integration Office at GSFC; SOCM estimate was within 10% of a separate grass-roots estimate performed by the project team.
JPL Project Design Center	SOCM is available at the PDC and has been used by several Earth orbiting and planetary mission concept development teams to validate their grass-roots estimates.
JPL Team X Venus Lander and Titan Aerobot/Lander Studies (Nov)	Provided independent operations estimates using the Planetary Module to Team X in support of two advanced mission concept definition studies; Results were within 5% of the separate Team X estimates

Figure 22, SOCM Study Applications

III. 1. 5. Future Plans

Future activities will focus on:

- Completion of the Planetary and Earth Orbiting Module Version 1.0 with integrated help menus and documentation,
- Completion of the Launch Systems Module incorporating MSFC, KSC, and LaRC inputs,
- Completion of the Space Facilities Module capturing the current ISS design with identified modifications to support lunar/Mars mission applications,
- Begin integration of operations modeling tools with other models to support life cycle analyses
- Development of initial RPMs to support HSF missions, and
- Continued support to the Steering Committee and SOCM user community.

III. 2. Air Force Cost Analysis Agency Taskings

III.2. 1. NAFCOM Related Taskings

There were several tasks funded by the Air Force Cost Analysis Agency that relate to the NAFCOM Cost Model. Progress made on each task is provided below.

III.2.1.1 Complexity Generator

The major efforts for the development of the Complexity Generators are described elsewhere in this final report. One specific action that the Air Force requested after reviewing the status of the Complexity Generators was to have someone with a strong statistical background review the development process. We have had two meetings with Dr. Steve Book of the Aerospace Corporation to get his input into our development of Complexity Generators. The latest meeting with Dr. Book included a briefing to Tony Fienfield and Lt. Col. Ray Carpio of the Air Force SMC/FMC. Dr. Book has suggested some new statistical approaches to the Complexity Generator development that are being incorporated.

III.2. 1. 2. PRICE Calibration

We are calibrating the NAFCOM Air Force normalized data to the PRICE model. The approach we are using is the same as the one developed for the NASA normalized data. We have completed the ECIRP runs to derive the manufacturing complexity factors and the forward run of the model to adjust the inputs to match the design cost for all the subsystem level data. We are currently completing the calibration of the system integration level data.

III. 2. 1. 3. Software Cost Separation Study

Currently the NAFCOM data base includes the cost of all software in the hardware cost. SAIC has completed a study on the separation of software cost from the avionics subsystems. In doing this study we determined which data points we had actual visibility into the software cost. Using these data points we developed an approach to normalize out the software cost for missions that did not have the required visibility.

Our initial look at the backup cost data for NAFCOM indicates some thirty-five missions that provide software costs. These data include flight and ground support equipment (GSE) software costs. Software costs in the NAFCOM backup information is evident in some twenty-five unmanned missions, six planetary missions, two manned missions, and several launch vehicles. The division of these missions and vehicles is good given the fact that most of these data points occur in the 1990s time frame. Many of the unmanned missions are also of the "low-cost" variety. Listed below are some of the missions that have software cost visibility.

MISSION	LAUNCH YEAR	MISSION TYPE
Lunar Prospector	1999	Planetary – Low Cost
Mars Global Surveyor	1998	Planetary – Low Cost
Step 3	1998	Earth Orbital – Low Cost
Lewis	1997	Earth Orbital – Low Cost
Mars Pathfinder	1996	Planetary – Low Cost
TOMS-EP	1996	Earth Orbital – Low Cost
NEAR	1996	Planetary – Low Cost
HETE	1995	Earth Orbital – Low Cost
STEP 2	1994	Earth Orbital – Low Cost
STEP 1	1994	Earth Orbital – Low Cost
STEP 0	1994	Earth Orbital – Low Cost
RADCAL	1993	Earth Orbital – Low Cost
ALEXIS	1993	Earth Orbital – Low Cost
MSTI	1992	Earth Orbital – Low Cost
TOPEX	1992	Earth Orbital
MICROSAT	1991	Earth Orbital – Low Cost
UARS	1991	Earth Orbital
GRO	1991	Earth Orbital
HST	1990	Earth Orbital
MACSAT	1990	Earth Orbital – Low Cost

Figure 23, Missions with Software Cost Visibility

III. 2. 1. 4. SEER Calibration Study

SAIC personnel met with persons from Galorath Incorporated to discuss the calibration of the NAFCOM data base to the SEER-H cost model. They expressed concerns over the lack of detailed cost and technical data at the sub-component levels. SEER-H requires input of the weight of electronics separate from the weight of structure within a subsystem. This requirement is similar to the input required for the PRICE model. We explained that our model is normally used in the early phases of a project and that low level input information is not available. They suggested an approach for the calibration that would not require the separation of circuit cards from the box. We are currently testing this approach with NAFCOM data and writing a report to document our planned approach to do this calibration.

III. 2. 1. 5. Data Collection

We have collected 13 new unmanned spacecraft data points for NAFCOM this year. In performing our normalization of the data, we have accounted for NASA ground rules and Air Force ground rules.

III. 2. 1. 6. NAFCOM Software Enhancements

We completed several NAFCOM software enhancements this year. We developed a new summary and note area that makes better use of the NAFCOM estimating screen. This data is shown on the upper right portion of the display and provides an place to enter notes on your estimating assumptions for each CER or displays a summary of the cost estimate.

We developed a new memo field in the project data base. This memo field includes a technical description for each of the subsystems in the data base. The memo field is accessed from the Specific Analogy screen within NAFCOM. As a user scrolls through the data points in the data base, the memo field displays technical data for the project that is selected.

We also completed a metrics conversion feature within NAFCOM. When creating a CER the user will have a choice of entering data in either metric or English units. After entering the data in one type of units, it can be converted to the other units by selecting a button.

III. 2. 2. AFCAA EELV Card Assessment

SAIC, utilizing expertise in our Colorado Springs office, provide the Air Force Cost Analysis Agency with independent cost and technical analysis and evaluations relative to the government's Acquisition and Operating and Support activities for the Evolved Expendable Launch Vehicle (EELV). Activities included comprehensive review of the EELV Cost Analysis Requirements Document (CARD) noting deficiencies, omissions, areas of potential misunderstanding, and errors. SAIC participate in Air Force reviews and reconciliation meetings.

Specifically, SAIC participated in the Cost Integrated Product Team (CIPT) meeting in Washington on February 2 and March 11-12 to summarize technical review findings on the EELV CARD. We reviewed the two EELV prime contractors' CARDs and prepared summaries of issues. SAIC reviewed on of the prime contractor's Downselect Design Review documents to assess their risk mitigation efforts. SAIC also participated in (1) the CIPT Status Review in Los Angeles on February 10-11 to review program office cost estimates and (2) a meeting February 23 in Colorado Springs to review manpower and cost estimates. SAIC performed seven Special Interest Items independent evaluations and one revised document review. Each evaluation was documented in a 2-3 page memorandum with specific technical review findings, complexity estimates, cost and editorial comments. SAIC also participated in the final reconciliation CIPT meeting in Los Angeles on April 16.

III. 2. 3. AFCAA EELV Economic Assessment

Cost and economic analysis support was provided to the AFCAA by participating on the Evolved Expendable Launch Vehicle (EELV) Investment/Financial Analysis (I/FA) Team. Support included participation in meetings to develop requirements and ground rules for a financial analysis model. NASA's Reusable Launch Vehicle (RLV) economic analysis was presented for consideration due to similarities of the two programs (i.e. both proposed the commercial development and operation of a launch vehicle system). Some features of the RLV model were incorporated in the EELV analysis. An EELV financial analysis model was developed in Microsoft Excel. It was designed to calculate EELV launch prices based on vehicle engineering and manufacturing development (EMD) cost, production cost, operations cost, industry rate of return, national mission model, and investment payback period. Other features included cost spreading by fiscal year, production learning, and income taxes. The model was instrumental in developing the Service Cost Position and for estimating savings over the current expendable launch vehicle baseline. Sensitivity analyses were also conducted to determine cost sensitivity to the baseline set of model input assumptions.

III. 3. COMPRE' Model

SAIC provided support to evaluate, review and validate the Complex Organizational Metric for Programmatic Risk Environments (COMPRE') model. The work was performed for the MSFC System Analysis and Integration Laboratory between June and November of 1998. This effort was a follow-on task to an initial COMPRE' model evaluation effort conducted in 1997.

The COMPRE' model, initially developed by MSFC and OR Applications, is an analytical program risk prediction model for aerospace hardware development programs. Utilized as a program management tool, COMPRE' takes into account program characteristics including schedule and budget, technology and their respective maturity, relative budget investment, system architecture, and organizational considerations. When executed, COMPRE generates relative risk and technology payoff values as a function of the aforementioned parameters. Comparing the values allows the end user to gain insight into technology utilization, their associated risks and payoffs, and interactions with program management parameters, in systems approaching or in a development phase.

The SAIC statement of work for this effort set forth the following tasks:

- Provide additional model validation and calibration (follow on to effort began in 1997)
- Conduct a pilot study of an existing MSFC project
- Investigate and evaluate of an off-the-shelf software tool for suitability as a host platform and user interface
- Provide data to OR Applications for continued theoretical development of the model

III. 3. 1. Model Validation

With respect to model validation and calibration, SAIC gathered historical cost, schedule and technology maturity levels from over thirty unmanned spacecraft programs. Once the data was placed into the COMPRE' model, results for programmatic risk and potential technology payoff were tabulated and graphed. Examples of the tabular and graphical outputs from COMPRE' are depicted below in Figures 1 and 2 respectively.

SYSTEM NAME:
MILESTONE: CDR (PPPR,ATP,PDR,CDR,DEL)
RUN NUMBER:

USER ENTRY					interfaces									
Duration	6.583333				Structure &	Thermal C	Electrical	CC&DH	Attitude C	Propulsion	Dewers	FIRAS	DIRBE	DMR
		description	budget %	devel matu	subsys1	subsys2	subsys3	subsys4	subsys5	subsys6	subsys7	subsys8	subsys9	subsys10
	subsys1	Structure & Mech	0.11	6		3								
	subsys2	Thermal Control	0.01	8	3									
	subsys3	Electrical Power	0.11	7				2	2		2	2	3	2
	subsys4	CC&DH	0.13	7			2		2			2	3	2
	subsys5	Attitude Control	0.09	8			2	2				2	3	2
	subsys6	Propulsion	0.00	8										
	subsys7	Dewars	0.21	8			2					2	3	
	subsys8	FIRAS	0.13	3			2	2	2		2			
	subsys9	DIRBE	0.15	2			3	3	3		3			
	subsys10	DMR	0.07	6			2	2	2					

RESULTS	
LAMBDA	26.498
SIGMA	30.655
RATIO	1.153

Figure 19, COMPRE' Tabular Output Screen

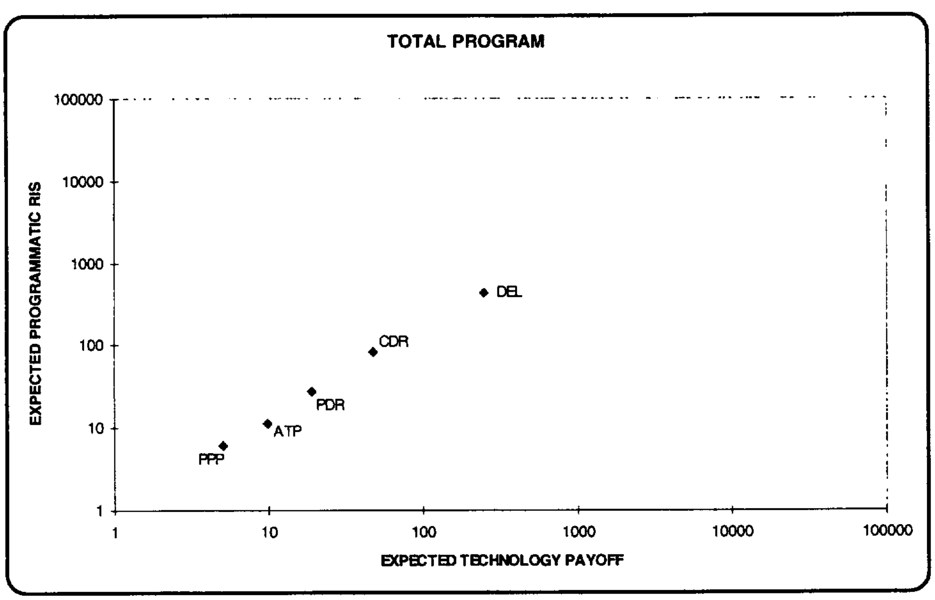


Figure 20, Program Risk vs. Technology Payoff Graph

When all of the analyzed programs were completed, composite charts depicting all of the Sigma (program risk) and Lambda (technology payoff) values were generated. This type of display is important to make a relative comparison of the programs. When graphed on a semi-log axis, the higher risk programs (i.e., higher Sigma value equates to higher program risk), with respect to each major milestone can be readily identified. This is shown in Figure 3. Likewise, the technology payoff chart, Figure 4, compares relative technology influences.

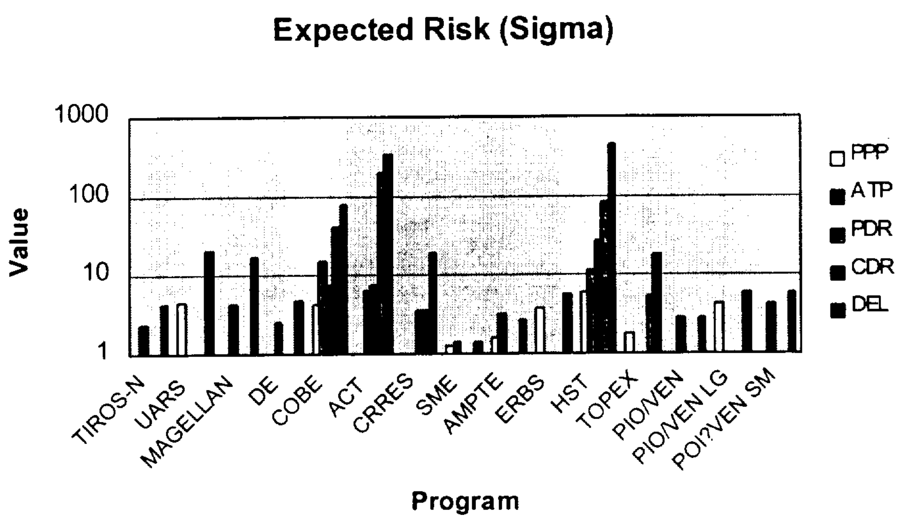


Figure 21, Comparison of Programmatic Risk

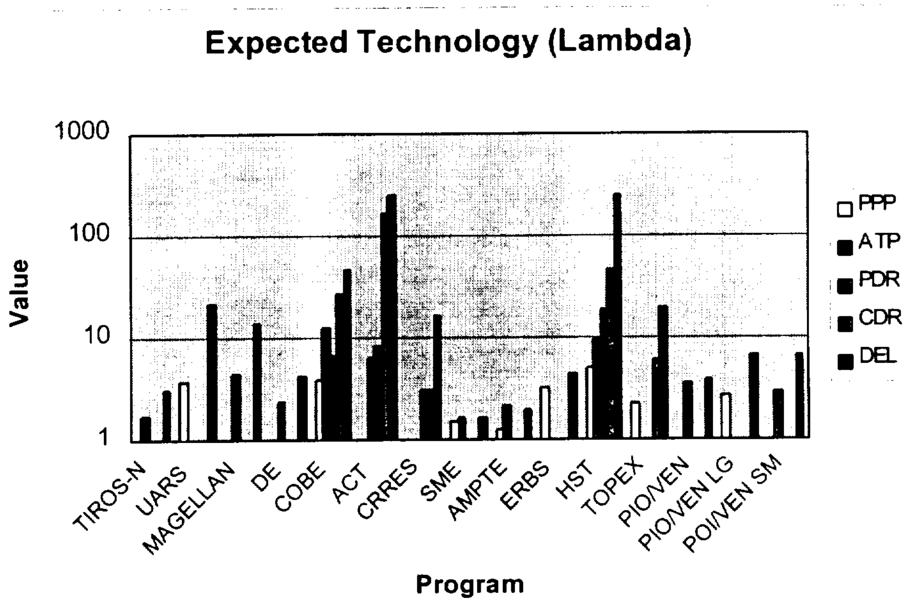


Figure 22, Comparison of Technology Payoff

III. 3. 2. Program Connectivity Diagram

We were also responsible for generating program connectivity diagrams. An example of a diagram is depicted in Figure 5. The chart shows how systems, and subsystems, are interrelated. Generating the diagrams assisted us with understanding how programs were constructed and served as a visual aid for data entry purposes. The interrelationships are one of the four primary parameters COMPRE' employs.

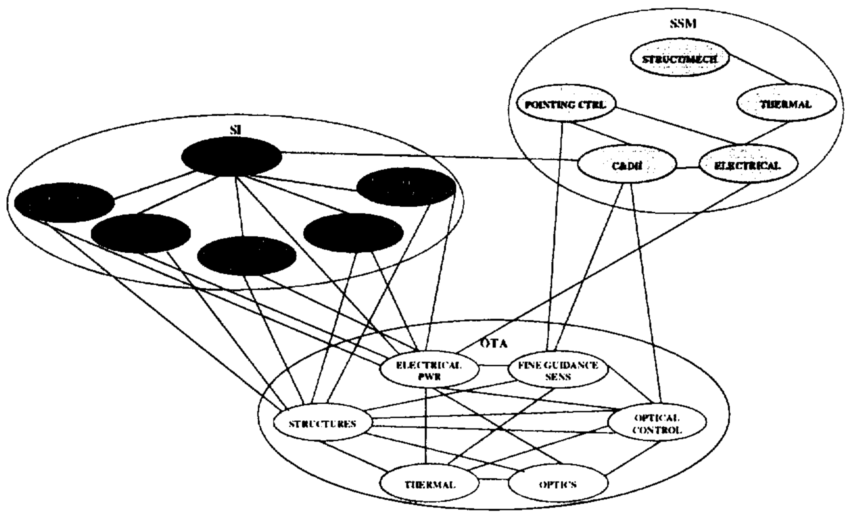


Figure 23, Interrelationship Matrix

III. 3. 3. Pilot Study

After the model's validation process was completed, we utilized the model in a pilot study program. Marshall's Materials Science Research Facility (MSRF) agreed to provide programmatic data on one of their scientific packages. We held several meetings with the MSRF staff explaining the model functionality and data requirements. Once the data was acquired, it was introduced into the COMPRE' model and analyzed. Due to the program's relatively short duration (approximately two and a half years), COMPRE did not produce unusual risk outputs. In fact, the overall program risk was comparable to other programs of the same duration and cost magnitudes. It was noted however that even though the program required foreign (European Space Agency) participation, the overall contribution, from this particular management requirement, to program risk was not significant.

III. 3. 4. Software Package Evaluation

SAIC was also responsible for reviewing and evaluating a software package (MultiLinx) that could serve as a front end user interface or graphical adjunct for the COMPRE' model. Multilinx is a unique connectivity visualization and analysis tool, which facilitates the design and integration of complex electro-mechanical and software systems. The software program was evaluated because of its ability to access data files and draw the components specified by the user and their connecting paths. This would facilitate the drawing of interrelationships as depicted in Figure 5.

After examining the program, we concluded that a considerable of amount of modification would be required to meet user (analyst's) requirements. Either the software manufacturer would have to create new input screens or in-house programmers would be required to write interface code so it may be used as an adjunct graphical tool. Both options are costly and would have to be evaluated further in follow on tasks.

III. 3. 5. OR Applications Interface

As program data was populated throughout the model and outputs were produced, reports were periodically given to OR Applications for additional data synthesis. OR Applications used the COMPRE outputs to justify model basis functions, and to assist in the overall model validation process. In addition, data packages including mission descriptions, COMPRE tabular output (reference Figure 1), graphical output (reference Figure 2), interrelationship matrices, and summary level data were provided to OR Application and the government. Periodic meetings with OR Applications and the government were held to discuss the data packages, measure task progress, plan upcoming events, and resolve any outstanding issues.

SAIC's one person at the Ames Research Center in California has assisted several local NASA teams in developing mission proposals and project cost estimates over the last year. We have provided many detailed cost estimates using various models and techniques. The tools used include NAFCOM 96, REDSTAR, SICM, The Estimators Toolkit, and various custom Excel models. Both parametric and grassroots estimates were provided. Some of the missions supported in the Option Year 3 follow:

III. 4. Microgravity Experiment Cost Model

The Microgravity cost support was renewed in this contract year. Under this effort we were to re-program and update the Microgravity Experiment Cost Model. Other work included the potential collection of new microgravity cost data with assistance from personnel at MSFC. Data collection opportunities did not materialize during the year. We have completed the re-programming of the model. The model now operates in the Windows 97 mode and that is a major step forward from the previous version. New screens have been created which will further enhance the capability of the model. The model now operates on both Mac and PC computers. The new models are being distributed to MSFC Microgravity personnel.

III. 5. PRICE Calibration

SAIC was tasked to continue to support NASA in calibrating the commercially available PRICE Cost Model for NASA users. Based on the response from the NASA community, this contract year we began calibrating the costs associated with integrating the subsystems into a system, or the Integration and Test (I&T) costs. This calibration is needed for an estimator to generate an estimate based totally on calibrated data. Since the PRICE calibrated data has been incorporated into NAFCOM at the subsystem level, it would be beneficial to have the calibrated integration and test values included as well.

The first step was to develop a methodology for calibrating PRICE's integration costs to NAFCOM's system level costs. SAIC worked closely with PRICE Systems personnel to develop a methodology that would correctly model and calibrate integration costs. The primary area of concern was how to model the System Test Hardware correctly. A cross section of data points were selected to be taken through the entire calibration process. This exercise allowed us to develop a methodology and PRICE factors for correctly calibrating System Level costs (or I&T costs). Adjustments were made as needed to the methodology and the selected data points were successfully calibrated.

At this point, it was decided that SAIC would perform a re-calibration of all data points in order to stay consistent with NAFCOM. This re-calibration effort involved the following:

> Calibrating to "As Reported" data instead of the current "Synthetic Wraps Applied" data.
>
> Incorporating Air Force projects.
>
> Calculating new complexity values (NEWST and ECMPLX) based on the Complexity Generator's TRL values.
>
> Calibrate integration values.

New complexity values (NEWST and ECMPLX) were calculated based on the NAFCOM complexity generator analysis. It was felt that more information was known now due to this study. Therefore, we incorporated this new information and adjusted our complexity values.

Currently we are in the process of calibrating to "As Reported" data. In order to do this process, spreadsheets were constructed which included the latest NAFCOM (NASA and Air Force) subsystem and system level cost data, complexity values, subsystem volumes, and development start dates. The platform values were reviewed and adjusted down slightly for the low-cost subsystems.

SAIC assisted PRICE in updating the model's integration terminology to reflect current applications and meaningful integration processes. They plan to convert the current INTEGE/S tables to a generator. SAIC provided PRICE with some input on NASA's System Level Elements since this was an opportunity to have PRICE incorporate some NASA practices into the model.

SAIC maintained contact with Del Wilson when possible through activity reports and phone conversations. We also assisted NASA PRICE Users as needed with PRICE questions.

The series of PRICE Models was installed on two SAIC computers through the NASA newly obtained site license. This allows for PRICE to be on more computers and is accessible without the toggle box used before.

III. 6. Ames Research Center Cost Analysis

SAIC's one person at the Ames Research Center in California has assisted several local NASA teams in developing mission proposals and project cost estimates over the last year. We have provided many detailed cost estimates using various models and techniques. The tools used include NAFCOM 96, REDSTAR, SICM, The Estimators Toolkit, and various custom Excel models. Both parametric and grassroots estimates were provided. Some of the missions supported in the Option Year 3 follow:

III. 6.1. KEPLER Mission

This is a spaceborn photometer that will be used to find the sizes, orbits and frequencies of terrestrial and giant extrasolar planets. This is a DISCOVERY class mission responding to AO 98-OSS-04. The estimate, accompanying cost documents in the required format and explanatory text were delivered to the principal investigator in June and the mission is currently under evaluation by the DISCOVERY Program.

III. 6. 2 VULCAN Camera

This is a ground based extrasolar planet search being conducted by the Space Sciences Division at Ames. SAIC has been involved in this project on a number of levels. We have provided cost estimates for several projects including an observatory Dome Automation Project (completed in February, funded in March); and a full two-option Extended Search proposal to the ORIGINS Program (completed in May, competitively selected, and funded in November). We are currently working on estimates for a small Shutter Automation Project and a WAN connectivity plan for a radio link between Ames and the observatory on Mt Hamilton.

III. 6. 3. MAGE Mission

The Mars Airborne Geophysical Explorer is a DISCOVERY class mission responding to AO 98-OSS-04. SAIC provided cost consulting and review services as well as assistance with the cost section of the proposal. We also provided costing feedback during the mission Red Team Review in May. The mission is currently under evaluation by the DISCOVERY Program.

III. 6. 4. FISCAT Program

The Far Infrared Survey Catalog is a Mission of Opportunity on the Japanese satellite ASTRO-F responding to AO-98-OSS-03. SAIC developed the cost estimate for the Ames portion of the mission and coordinated the cost assessment for the remaining U.S. segment of the mission. The estimates were culminated and the required documents were delivered in August. The mission is currently under evaluation by NASA Headquarters.

III. 6. 5. SHARP-FX Mission Suite

The Slender Hypervelocity Aerothermodynamic Research Probes are a series of reentry probe TPS technology demonstrators responding to the FUTURE-X Pathfinder Flight Demonstrators Program, NRA 8-22. For this mission, SAIC provided a complete end-to-end cost analysis of two reentry vehicles including the full set of the accompanying documents required by the NRA. These were finished and delivered in September. The mission is currently under evaluation by the FUTURE-X Program.